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PROTECTION AGAINST HEAT LOSS AND MECHANICAL EQUIPMENT OF BUILDINGS IN THE NORTH

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ABSTRACT

The book deals with the meterological factors influencing buildings, presents an analysis of their influence on the heat regime in buildings, and presents the results of physical and hygienic studies of temperature comfort for human beings in residential buildings. It also includes recommendations for heat engineering calculations and the design of outside walls, taking into account requirements that are set by the specific conditions existing in the far north. Recommendations are given for the construction of systems of mechanical equipment for buildings: heating, ventilation, water supply, sewers and gas pipes under extreme climatic conditions. The book is intended for engineers and technicians working on the design and construction of buildings for the northern construction climate zone.

FOREWORD

Its enormous reserves of energy resources, its unique non-ferrous metals and minerals, and its forest and fish reserves place the northern part of our country among the most economically promising regions, and this has triggered the investment of dozens of billions of rubles for the next 10-12 years.

In studying problems associated with the conquest of the north it is necessary to take into account the characteristics and specific features that are found there: the remoteness from developed areas of the country, the lack of permanent transportation links between the zone and the developed industry for construction materials, the random distribution of its enterprises, and the high cost of the work force. The harsh climatic conditions in the north, characterized by low temperatures of the outside air, with considerable daily variations, strong winds, heavy snowfall and intensive rain, make it particularly important to take all of these factors into account when designing and constructing buildings.

Very strict requirements are imposed on construction work in the north, because the proper microclimate must be created in the buildings, and the quality of the buildings must be such from the sanitary engineering and physiological standpoint that they will provide the necessary conveniences of life for the people who live in them, and the economic factors will be favorable as well - such things as reducing the difficulty of labor and increasing the level of industrialization of construction, long service life, reduction of capital and operation expenditures.

The Communist Party of the Soviet Union, acting through its Central Committee and the Council of Ministers of the USSR, has laid down a broad program of measures aimed at increasing the quality of the design and construction of cities and populated areas, further development of a complete range of house building and an increase in its technical level, development of the production of materials, products and equipment for residences.

In addition, the construction of buildings in the northern construction climate zone in many cases is carried out on the basis of projects that were developed for the central part of our country, without taking into account the special characteristics associated with northern regions. It is therefore necessary to develop very rapidly, specialized projects for houses and buildings to be used for cultural and residential purposes, making it possible to achieve an important qualitative change in the urban construction to be carried out in this enormous area.

In view of the harsh natural climatic conditions, the population living in the north must be provided with housing which is as warm and comfortable as possible and has a full range of available equipment (water supply, sewage, central heating, hot water, electric and gas cooking, etc.), despite the magnitude and administrative or economic significance of the city or settlement.

Something which is of primary importance for the north is the protective measures to be taken against the harmful effects of climatic conditions on man. This is equally important both for separate buildings and for the populated areas as a whole. Depending on the climatic conditions of the different subzones of the north - the snow cover, wind velocity, temperature level- it is necessary to provide appropriate measures for the construction of protection against snow and wind and to make the microclimate less harsh in the inhabited area and to ensure that the buildings are suitably comfortable.

From this point of view, the solution of problems relating to the scope of planning is very important, ensuring that they are simple in shape and have compact volumes, making it possible to reduce the general heat losses through the walls, to insulate as much as possible the residential buildings and those used for cultural purposes, to build them to face the sun, and also to give some attention to the interiors of the buildings. In order to carry out these tasks it is necessary to work on all the requirements that are involved in the planning and construction of modern buildings. The requirements for reliable heat protection of the equipment and providing the comfortable microclimate in the residences in the north are largely determined by the climatic region of the construction as well as the ethnographic and demographic features of the population. Unfortunately, all too often these factors do not receive the

attention they deserve in planning, and in some cases they are even ignored due to a lack of sufficient recommendations.

The development of the construction industry, which is usually a stimulating factor for scientific research, often considerably outstrips the results in the light of the standard requirements for the planning and calculation of buildings and structures on the whole. Therefore, the results of the laboratory research on new structural solutions, natural testing of experimental samples under conditions resembling the actual ones, make it possible to take into account specific features of newly developed structures and buildings and also the influence of the external factors acting upon them.

In order to assist in planning on the basis of theory and practice in the field of structural thermophysics, experience in planning and building research as well as their engineering resources, we have written this book. The authors do not pretend to originality nor do they claim that this book is particularly distinctive; rather, they have simply tried to carry out a process of selection which will make the necessary material available and will present a critical analysis of the existing construction experience in the north, systematizing the data and recommendations that are needed for each situation.

CHAPTER I

CLIMATIC INFLUENCES ON BUILDINGS, AND TAKING THEM INTO ACCOUNT IN PLANNING

There is a constant exchange of heat and mass through the outside walls of buildings, depending on the effects of the external air and the influences on the microclimate of inhabited buildings. Therefore the daily and annual variations in temperature of the outside air (during both the cold and warm seasons of the year) the humidity and speed of the air, the level of atmospheric pressure, solar radiation, amount of precipitation, etc. are the most important factors which have a perceptible effect upon the temperature and humidity conditions and the operational characteristics of buildings, as well as the changes in temperature and humidity of the inhabited structures and their individual layers.

In many cases, not only is there a separate influence inserted by various factors, but they also act jointly, for example, the wind and low temperature operate simultaneously, as do wind and rain, snow and wind.

In the heat engineering calculations for the outside walls it is important to know not only the quantitative values of the critical meterological factors, but also the characteristics of their effects upon buildings, taking into account the natural climatic zones of the enormous territory of our country. In each specific case, the measures for protecting buildings against climatic effects will depend to a large degree upon the architectural and planning organizations for residences and the functional purposes of the buildings.

CALCULATION OF THE TEMPERATURE OF THE OUTSIDE AIR AND THE REQUIRED HEAT INSULATION CHARACTERISTICS OF THE WALLS

One of the principal functions of the walls is to protect the building against cooling under the influence of low temperatures of the outside air. The temperatures are not the same in different geographical points and depend upon the season. Therefore in order to calculate the heat-protection properties of the walls of a structure one must determine the computational temperature of the outside air for each geographical area. Its value is determined on the basis of meteriological data for the 16 coldest winters from a period of at least 50 years. In the computation, the average temperature of the outside air of the coldest period of time is used, under whose influence the temperature on

the outside surface of the wall drops to the minimum allowable level from the sanitary engineering standpoint. The time required to reach this temperature depends upon the heat-insulating properties of the construction of the wall.

In determining the heat-protective properties of the walls the values for the computational outside temperatures $T_{outside}$ are determined on the basis of the degree of massiveness of the construction, the characteristic value of thermal inertia. The so-called conditional thickness of the construction is used for this purpose as proposed by Prof. O.Ye. Vlasov [2]. It has nothing in common with the usual concept of the geometric thickness of the walls and is a dimensionless criterion, characterizing the number of temperature waves which are damped in the thickness of the structure under the periodic influence of such waves upon one of the outside surfaces.

Structures whose thermal inertia values are greater than 7 are considered massive, those from 4 to 7 are moderately massive, those from 4 to 2 are light, and those less than 2 are particularly light. On the basis of this classification, massive walls include those that are 0.6 m or more thick, made of solid clay brick and slag-concrete blocks with a density of 1600 kg/cm or more; walls of medium massiveness are those made of lightweight perforated brick, hollow ceramic, cellular concrete and other similar material; light walls are the most widespread designs of roofs without attics, large-panel wall designs, heated by light heat-insulating materials; particularly light designs are those which are made of thin high-strength sheet material and highly efficient sealers.

The determination of the duration of the cooling process of the walls has shown that the established most unfavorable thermal condition for solid walls corresponds to the calculated temperature of the outside air which is equal to the temperature of the coldest five day period.

Since the cooling time of the thin and light walls is calculated in hours, it is calculated on the basis of the average temperature of the coldest days. In the northern construction climate zone, the values of the computational temperatures for light construction show considerable variation from -25 to -65°C.

In the case of walls of medium massiveness, the computational value is the temperature equal to the halfsum of the coldest days and five day periods.

The permissible cooling of the inside surface of a wall is determined by the difference in the temperature of the inside air and the temperature of the inside surface of the wall

τ_B, i.e., $t_B - \tau_B = \Delta t^H$. The value of Δt^H is a function of the nature of the surface (wall, ceiling, floor) and the purpose of the structure.

The amount of heat which is absorbed by the inside of a dwelling is proportional to the coefficient of heat perception α_B (in kcal/m^2.hour.°C) and the temperature difference Δt^H, and the amount of heat which is given off from the inside air to the outside through the wall is proportional to the total coefficient of heat transmission k_O (in kcal/m^2.hour.°C) and the temperature difference between the inside and outside air $t_B - T_H$. At a stable temperature state, both heat fluxes are quantitatively equal;

$$\alpha_B \Delta t^H = k_0 (t_B - t_H). \tag{1}$$

from (1) it follows that

$$k_0 = \alpha_B \Delta t^H / (t_B - t_H). \tag{1a}$$

In calculations in structural thermophysics, the concept of "resistance to heat transmission" is usually employed, i.e., a value which is the reciprocal of the coefficient of heat transmission, $R_O = 1/k_O$ (in m^2.hour.°C/kcal). The value of the minimum permissible (required) value of the total resistance to heat transmission, which a wall must have under certain conditions - the inside temperature, the calculated temperature of the outside air in the geological point in question, the permissible value Δt^H and the position of the wall are determined by the formula

$$R_0^{\text{TP}} = (t_B - t_H) n / \alpha_B \Delta t^H, \tag{2}$$

where n is the numerical factor which depends upon the purpose and location of the building. The values of the parameters that are necessary for substitution in formula (2) are obtained from the tables (SNIP II-A, 7-71 and SNIP II-A, 6-72).

In the designs of walls their heat protective properties are bound to conform to the required standards if the magnitude of the total resistance to heat transmission R_O, calculated on the basis of the formulas given below, is equal to or greater than the standardized value for this parameter R_0^{TP}, determined on the basis of equation (2).

The total resistance to heat transmission of a 1-layer wall is equal to the sum of the individual resistances:

$$R_0 = R_B + R + R_H,$$

where R_B is the resistance to heat transmission on the inside surface of the wall, m^2.hour.°C/kcal;

R is the thermal resistance of the construction, m^2.hour.°C/kcal;

R_H is the resistance to heat transfer to the outside surface of the wall, m^2.hour.°C/kcal.

The heat resistance of a homogenous wall design or an individual layer of a multilayer design (in m^2.hour.°C/kcal) is determined by the formula:

$$R = \delta/\lambda,$$

where δ is the thickness of the structure or the wall, m;
λ is the coefficient of thermal conductivity of the material, kcal/m.hours.°C

The thermal resistance of a multilayer wall of a structure is equal to the sum of the thermal resistances of all of its individual layers:

$$R = \sum R = \delta_1/\lambda_2 + \delta_2/\lambda_2 + \ldots + \delta_n/\lambda_n. \quad (3)$$

The expression for calculating the total resistance to heat transmission of a multilayer construction has the form:

$$R_0 = R_в + \delta_1/\lambda_1 + \delta_2/\lambda_2 + \ldots + \delta_n/\lambda_n + R_н. \quad (3a)$$

When there is an air layer in the design, the value of its resistance to heat transmission must be included in the formula ($R_{в.п.}$, and it has the following form:

$$R_0 = R_в + \delta_1/\lambda_1 + \delta_2/\lambda_2 + R_{в.п} + \ldots + \delta_n/\lambda_n + R_н. \quad (3b)$$

The choice of the computation of temperatures for the outside air in determining the required resistance to heat transmission $R_0^{тр}$ is carried out in accordance with the recommendations of SNIP II-A, 6-72.

VARIATIONS IN THE TEMPERATURE OF THE OUTSIDE AIR

In all climatic regions the temperature of the outside air is not constant as a function of time, and therefore is not constant in magnitude; neither is the heat flux through the wall from the inside air to the outside. In some areas where there is a harsh climate the daily variations in the temperature reach 25-30°C, which has an extremely unfavorable effect upon the condition of the outside walls. Therefore, in designing the latter, it is necessary to take this factor carefully into account.

The daily variations in the temperature are taken into account in the thermal physical calculations of the temperature resistance of the walls. They are of interest in conjunction with estimating the probable service life of many building structures, especially the outside walls that are moistened by atmospheric moisture. The annual variations in temperature of the outside air are taken into account in determining the differences between the temperature levels of the equipment.

Variations in the temperature of the outside air cause temperature variations not only on the outside surface but also within the wall itself, leading to precipitation, thermal stress, swelling and other phenomena within the structural material itself, which breaks as a result. Therefore, there is an increasing tendency to use those types of construction in which the outside parts are damaged by moisture and active solar radiation i.e. the sunward walls and the parts of the roof that are heated most.

Considerable disruptive affects upon the outside wall structure of buildings are exerted by the alternation of positive and low negative temperatures in the outside air, causing water to freeze in the structural material. During the intermediate times of year, the temperature increases of the outside air which take place are very dangerous since they are accompanied by rainfall which moistens the outside layers of the structure and subsequent temperature drops which cause the moisture to freeze. The faster the outside part of the building freezes, the more severely it is damaged.

The major part of the moisture freezes in the pores of the material when there is a sharp drop in the air temperature after a thaw, which occurs during periods when there is a sharp drop in temperature, for example, in December, January and February. In many areas the thaws during this season of the year last more than 24 hours, and alternate with sharp drops in temperature. The thaws that are accompanied by the precipitation and the formation of fogs cause considerable wetting of the outside parts of the wall.

SOLAR RADIATION

The use of large surfaces covered with glass in modern structures requires that certain structural problems be solved which take into account insulation and make it possible to develop solar insulation for buildings not only for southern regions, as would appear at first glance, but for those that are located at high latitudes. At the present time these problems are being taken into account in such northern countries as Finland, Sweden, Canada and so on.

During the period from April to August, even in northern regions, the surface of the glass which faces the southwest is often so much heated on sunny days that negative conditions for human vital activity are created inside the building. This is due to the low position of the sun, at which the rays are almost perpendicularly directed onto the surface of the walls and the windows.

It should be remembered that the window glass is transparent to heat flow originating at the sun. The influx of heat into the building increases its losses considerably, so that not only in summer but even in winter there may be overheating of the buildings that are facing the south. This phenomenon creates several possibilities (not all of which have been considered practically as yet),for reducing the computed surfaces for heating of the heating devices for the building.

We distinguish between two kinds of solar radiation: the direct kind, which is the measured amount of heat which is carried by solar radiation, striking directly on the surface of a structure, and the scattered radiation, which arises as a result of the diffuse reflection of solar rays from clouds, droplets of moisture and dust, found in the layer of the atmosphere closest to the ground.

The heating of the walls is affected both by direct radiation and by scattered radiation. Therefore, in our thermotechnical calculations we must take their total into account - the total radiation which is expressed by the total heat effect of solar radiation. The amount of direct and scattered radiation, absorbed by the surface of a wall, depends on the angle at which it is inclined to the horizon, the orientation relative to the light side, and also upon the color and nature of the roughness of the surface.

Radiation factors are of considerable importance in the formation of a temperature regime for buildings and walls under severe climatic conditions. It is particularly important to take solar radiation into account in certain areas (for example in the Transbaykal), which are characterized by considerable numbers of days in winter when the sky is clear, so that the maximum amounts of heat from solar radiation strike the vertical surfaces that face south. Here a considerable number of temperature transitions through the 0°C mark can be seen, up to 150 times, creating additional temperature stresses in the elements of the walls of the building.

In schools and other buildings that are used for public purposes it is necessary to provide protection against the direct impact of solar radiation during the school day or work day, in order to eliminate the blinding effects.

EFFECT OF AIR EXCHANGE ON THE TEMPERATURE REGIME IN BUILDINGS

The outside walls of buildings are always exposed to the effects of differences in pressure which arise under the influence of the wind or temperature differences between the inside and outside air. The difference in pressure is the reason for the movement of air through the pores of the structural materials, holes and gaps between their parts, with the air moving from the area of high pressure to low pressure.

In general, this process is referred to as air penetration or filtration. The penetration of air from the outside to the inside of a building is called infiltration and from the inside of the building to the outside - exfiltration. When the air is passing through the wall in a direction which is perpendicular to its surface, transverse or through filtration takes place. However, when the air penetrates the wall and then is diffused along the structure inside it, transverse filtration takes place.

In the case of filtration of colder outside air which is at a lower temperature than the inside air, the temperature in each cross section of the wall drops so that the thermotechnical properties of the wall structure deteriorate and excess heat is used for warming the air penetrating into the building. In addition, for sanitary and hygienic reasons, air exchange in buildings is necessary and consequently it must be provided for to a degree which will meet hygienic standards. SNIP II-A.7-71 allows for infiltration of the air through the outside walls of residences at a rate of no more than 0.5 kg/m^2.hour.

The distribution of air pressure inside a building is a function of its geometric shape, aerodynamic characteristics, the height of the building, the magnitude of the temperature head, the degree of insulation of the individual stories or groups of buildings from one another, the protection against the action of the wind, and other conditions. The temperature head in multistory buildings causes the infiltration of the outside cold air through the outside walls of the building on the first few floors and exfiltration of the warm air from the residences in the upper part of the building. These phenomena are particularly noticeable in severe frosts, when the temperature difference between the inside and outside air of heated buildings is greatest.

The air from the apartments on the lower floors, under the influence of the temperature head, flows up the staircases, elevator shafts, ventilator shafts, and sanitary engineering pipes or through the permeable coverings into the apartments on the upper floors, and through them out through holes in the outside walls.

Between the areas of infiltration and exfiltration there is a neutral zone, in whose plane there is no air movement. When the levels are completely separated, the neutral zone will be located on each floor, and when there are connections between them, there will be one neutral zone whose location can be determined by the total air exchange in the building. In the event of an increase in the volume of infiltration the neutral zone will drop within the building, and when exfiltration increases (for example, when windows are opened in the upper floors) the neutral zone will move upward. When there is no wind and the systems for natural ventilation which are usually employed in modern residential structures are incorporated in the building, the neutral zone will be located at a point 0.6 to 0.7 of the height of the building.

Under the influence of the wind head the outside air will penetrate the building through holes in the outside walls, located on the windy side, and will pass through the walls on the lee side.

In modern construction, the penetration of air and the exchange of air in buildings are of great importance, especially in multistory buildings with thick-panel design and separating elements between which there are continuous butt joints. Therefore, in buildings made of panels, particular attention must be paid to measures aimed at sealing up both the vertical and horizontal joints between the outside wall panels, coverings and coatings. As we mentioned earlier, under the influence of the temperature head, the air passes from the lower stories to the upper stories, so that hermatic sealing of the coatings is of particular significance.

It is advantageous to seal the doors of the apartments of both the lower levels, through which the air enters the staircase, and the doors of the apartments on the upper floors, through which the air passes when it comes out of the staircase into the apartment. In the case of buildings with a great number of stories, these measures are inadequate, since considerable temperature heads are operating in them on the lower floors, reaching 15-16 mm water column. In such buildings, besides blocking the doors of the apartments, it is recommended that the staircases be provided with air locks or that some kind of bulkheads be provided in the staircase. Similar measures are recommended for planning the elevator shafts in tall buildings providing access to the elevators not from large vestibules, but from small areas with automatically closing doors.

The proper organization of ventilation systems is extremely important, especially in buildings that are eight stories tall or more. On the lower levels, it is only possible to provide exhaust systems for places where harmful substances are released. In the apartments on the upper floors it is

necessary to provide for some kind of an intake ventilation system, thereby reducing rarefaction and lowering the rate of infiltration on the lower floors, while the apartments on the upper floors are thus provided with a good supply of fresh air.

In order to reduce air exchange under the influence of the wind, it is advantageous to build some barricades that prevent the air from flowing through the building from the windy side to the lee side. For this purpose, it is important to provide dense barricades and a close fit for the doors to the apartments, especially those that face on both sides of the building. A very perceptible result can be seen when the apartment does not have through ventilation, in other words when all the windows of the apartment face the same side of the building.

Infiltration in the lower stories and exfiltration in the upper stories lead to a drop in the air temperature in those apartments which are below the neutral zone and a slight increase in temperature in the upper floors. Taking into account the considerable influence of air filtration in buildings with a great number of stories, it is necessary to pay particular attention to the sealing of the walls, coverings, and roofs, so as to ensure the exchange of air by controlled means which is necessary for comfort.

The kinetic energy, or the velocity pressure of the wind (in kgs/m^2) is determined by the following expression*

$$p = v^2 \gamma_t / 2g, \tag{4}$$

where v is the velocity of the wind, m/sec.;
γ_t is the specific gravity of the air at a given temperature, kg/cm;
g is the acceleration due to gravity, 9.81 $m/sec.^2$.

As we can see from formula (4), the kinetic energy of the wind is in a quadratic relationship to its velocity. A certain influence is also exerted by the specific gravity of the air: at a given wind velocity, the value of p will increase if the air is at a lower temperature. At 0°C and 760 mm Hg the specific gravity of air is 1.293 kg per cm, and at a temperature t the specific gravity is determined from the relationship

$$\gamma_t = \gamma_o \cdot 273/(273 + t).$$

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* In the present paper, as in the current SNIP specifications and the literature on the temperature physics of construction, the measurement unit "specific gravity" and "volume weight" are used instead of the recommended "density" and "volume mass" ($\rho = \gamma/g$). For the conversion of the measurement units that are used in the book to the SI system, see Appendix 3.

The wind velocity increases with distance from the ground. This is due to the decrease in the force of friction of the air against the ground. The expression for the change in wind velocity with altitude is expressed by the formula

$$v/v_0 = \sqrt[4]{h/h_0}, \tag{5}$$

where v is the measured wind velocity at an altitude h, m/sec.;
v_o is the known wind velocity at altitude h_o from the ground, m/sec.

The pressure of the wind against the wall of a building is determined by using the formula (4) introducing the correction factor for aerodynamics K_{aer}, which depends upon the shape of the building and the position of the wall relative to the direction of the wind:

$$p_н(p_з) = K_{аэр} v^2 \gamma_t / 2g, \tag{6}$$

In the case of multistory residences with the simplest rectangular shape in cross-section, the values for the aerodynamic coefficients can be assumed equal to 0.8 with a "+" sign on the windy side and 0.6 with a "-" sign on the lee side.

Inasmuch as the direction of the wind changes a great deal in flat areas, one side of the building may turn out to be always exposed to the wind if it is not protected by other structures or by natural obstacles.

The difference in air pressure (in kgs/m^2) on both sides of the wall under the influence of a temperature head

$$\Delta p = h(\gamma_н - \gamma_в), \tag{7}$$

where γ_n, γ_b are the specific gravities of the outside and inside air, respectively, kg/m^2;
h is the vertical distance from the point in question to the neutral zone, meters.

The total calculated difference in air pressure (in mm water column) on both sides of the wall in buildings that are equipped with natural exhaust ventilation, can be determined for the lower story of the building from the expression

$$\Delta p = 0{,}55H(\gamma_н - \gamma_в) + 0{,}03\gamma_н(\beta v)^2, \tag{8}$$

where H is the height of the building in meters;
v is the calculated wind velocity determined on the basis of data from SNIP II-A.6-72, m/sec.;

β is a coefficient which takes into account the non-correspondence in time of the calculated wind velocity and the calculated outside temperature, determined on the basis of the recommendations of SNIP II-A.7-71.

By analogy with the resistance to heat transmission for thermophysical calculations, the concept of resistance to air penetration has been introduced, which expresses the filtration of the airflow by the wall structure as a whole or by its individual structural layers. The resistance to the penetration of air R_i is measured in mm of water column per m^2/hour/kg and represents the difference between the total pressures at which the air flow through 1 m^2 of the wall per hour is 1 kg.

The resistance to the penetration of air of a homogenous layer of material which has no joints or cracks is determined by the formula

$$R_{и} = \delta / i, \tag{9}$$

where δ is the thickness of the structural layer, meters;
i is the coefficient of air penetration, kg/m/hour/mm water column.

The determination of the value for the resistance to the penetration of air of a laminated wall is accomplished using the expression

$$R_{o.и} = R_{и1} + R_{и2} + \ldots + R_{иn}, \tag{10}$$

where R , R ,...R is the resistance to the penetration of air of individual structural layers of a wall, mm of water column/m^2/hour/kg.

In order to eliminate undesired cooling of the wall structures and an excessive loss of heat for heating the outside cold air, penetrating the building as a result of the penetration of the air, structural standards and regulations have established a number of requirements that limit the permiability of structures as a whole or their individual structural layers.

By analogy with the determination of the values of the total required resistances to heat transmission $R_o^{тр}$, the value of the total required resistances to air penetration have been determined, $R_o^{тр}$ for the wall structures (in mm of water column/m^2/hour/kg)

$$R^{тр}_{o.и} = \varepsilon \Delta p, \tag{11}$$

where ε is the coefficient which is used for outside walls and coverings above passageways, equal to 2, for attic coverings - 1.5.

Formula (10) assumes a homogenous direction for the flow of air through the outside structure of the wall (through filtration). This phenomenon occurs in structures that are made of several layers of different homogenous materials, which do not have significant thicknesses. In multilayer structures, whose individual layers differ significantly from each other as far as their degree of resistance to filtration is concerned, and the connections in the planes of contact between the layers have considerable leakage, this phenomenon of through filtration will not take place. In this case the flow of air which is directed through the wall, reaching the surface of a denser layer, will be distributed parallel to the surface, forming longitudinal filtration. For this case formula (10) is not exact, since the principal value for $R_{o.n.}$ has a dense outside layer and the following layers are insignificant.

It follows from the above that it is more correct to determine the total resistance to air penetration of a structure on the basis of the resistance of its densest layer, which is supposed to be located closest to the outside surface.

The amount of air passing through the wall in through filtration (in kg/m^2/hour) may be determined by the expression

$$G = \Delta p / R_u. \tag{12}$$

In a design project, on the basis of the frequency with which the wind in a given area blows from a given direction, it is necessary to determine which sides will be subjected to the influence of the wind most often. In the case of very frequent and sharp effects of this kind, it is necessary to provide special protection against the air passing through the walls that are located on the sides of buildings that face the sea, the outlets of valleys, and other kinds of terrain which are not protected from the wind.

The temperature and wind characteristics of the northern structural and climatic zone can have a considerable influence upon the heat losses of the buildings and the values of mass exchange, and consequently upon the temperature field of the outside walls. The zone with the least favorable temperature and wind effects from the outside environment is found on all of the northeastern coastal areas of the country and some areas in western Siberia and maritime territories. Here the low temperatures of the outside air always coincide with prevailing winds from certain directions. Therefore, the walls which are on the windy side are exposed to the most serious operating conditions and require additional heating and weatherproofing or appropriate planning measures that would improve their protection against temperature.

The orientation of the walls which are subjected to the most unfavorable affects of cold wind differ for different parts of the country: thus for example on the northern coast of the Kola Peninsula the prevailing wind in winter is from the south and is an average of 8-10°C colder than the one from the north; in the maritime costal areas the northern orientation is the least favorable one; in the inner regions of Kamchatka it is the southwestern exposure which is worst.

On the northeastern coast of the USSR, the average monthly wind velocity in January is more than 5 m per second, and in some places 8 m per second. When we calculate the infiltration of the outside walls and estimate the total heat losses it is necessary to take into account the wind velocity which corresponds to a given climatic region.

MOISTURE OF THE OUTSIDE AIR AND THE HUMIDITY CONDITIONS IN THE WALL

The moisture content of the air in a given geographic region is determined by the action of air from bodies of water upon it. In territories which are far away from such influences, stable masses of continental atmosphere prevail with a characteristically low relative atmospheric humidity. However, this kind of relatively low humidity is also observed in territories which are close to bodies of water but are remote from mountain ranges.

The average humidity per month for large areas of the USSR which are remote from oceans and are subjected only to the action of moist winds is as a rule constant at certain air temperatures.

On the basis of meterological data, the characteristics for the variation of the average monthly values of the partial pressure of the water vapor in the outside air have been determined in various parts of the USSR as a function of the average monthly values of the outside temperature.

During the winter deviations from the average values of the relative humidity of the outside air are insignificant in all areas where there is a constant snow cover, since the latter to a large extent is responsible for regulating and balancing out the humidity in the layers of the air near the ground. In areas where the snow cover is not always present the relative humidity during winter decreases significantly. During the warm time of the year (May through September) it varies within much greater limits than in winter, since it is subjected to the influence of precipitation and the amount of solar radiation, the repetitive nature of the effects of the continental dry and marine wet air also make themselves felt.

The majority of structural materials and equipment contain natural and synthetic moisture. Parts made of concrete, slag-concrete, plaster, lime in particular have a large amount of synthetic moisture in them, especially if they have not been dried out beforehand. Materials and equipment which do not contain synthetic moisture, such as brick, ceramic, etc. can get wet during shipment, storage and during manufacture.

All of this means that during the initial period of operation of buildings their walls have an increased content of moisture and give it up to the outside or inside air. A considerable reduction of the structural moisture can be promoted by using walls built of ready-made materials - panels, blocks or sheets.

In order to dry out the parts or the structure to get rid of the moisture it is necessary to be able to reach the surface for evaporation. The distance required is determined by the so-called applied thickness of the structure - the ratio of the total volume of material to the outside surface of the structure. If the composition of the structure involves materials with hollow spaces in them or brittle materials with large pores, the evaporation process would take place not only from the outside surface of the building but also from the inside surface of the spaces or pores, thus speeding up the drying process.

The outside climate has a direct influence upon the moisture content of the structure. A considerable influence is exerted by the amount of natural heat in a given climatic region, expended in the natural drying of the wall structure. The effectiveness of using it is governed by the nature of the moisture exchange between the surface of the structure and the surrounding air. Structures which are heated and cooled periodically dry out more rapidly than those that are subjected to irregular and prolongued heating with the same heat loss.

It is precisely this phenomenon which is characteristic of regions with a continental climate where the temperature changes sharply in the course of 24 hours, thus intensifying the drying process. Under these climatic conditions, where fewer temperature variations are seen, the humidity of the air and materials in the walls, all other conditions being equal, usually decreases more slowly.

It is important to determine the general characteristics of the climatic region from the standpoint of the process of natural drying of structures. For this purpose it is necessary to determine the relationship between the most important factors that affect this process: the amount of precipitation which moistens the structure P (in kg/kg) each year; the relative humidity of the outside air, ϕ; the

amount of solar radiation Q_s (in kcal/m^2/year); the amplitude of the fluctuations in the temperature of the outside air A_t (in degrees) and to express their mutual influence upon the process of each kind of resultant value which takes into account the humidity conditions of the structure. This kind of an interrelationship can be expressed by the following:

$$\omega = P\varphi / Q_s \sqrt{A_t} = f(K). \qquad (13)$$

The humidity-climatic classification of regions for construction involve three zones each of which is broken down into two categories of regions:

1) A dry zone with K < 5 is divided into the following regions: constantly dry (K <3) and dry (K =3-5);

2) A moderate zone with K = 5-9 is divided into regions as follows: moderately dry (K = 5-7) and moderately moist (K = 7-9);

3) A wet zone with K >9 is divided into the following regions: wet (K = 9-11) and always wet (K >11).

Structural materials and equipment differ markedly in the rate and degree to which they dry out even under identical meteorological conditions, since they have different thermophysical properties, related to the volumes of the parts and their surfaces, the nature of the relationship between the moisture and the surface of the pores in the materials, and the moisture conductivity.

Structures that dry out slowly retain their moisture at high temperatures of the environmental air. Therefore, if they cannot dry out before the period during which the outside air temperature falls, they will be moistened once again by atmospheric and diffusing moisture, and would practically never dry out but would remain chronically damp. Rapidly drying materials and equipment during the warm period of the year almost completely give up their moisture to the outside air.

In climatic regions with a high humidity in the air and a moderate temperature, there is a considerable positive influence exerted upon the drying process of the walls by constant winds. They activate the loss of humidity from the surfaces of the walls and speed up the drying process.

Freshly built walls have reduced heat protective parameters in comparison with those that have been dried. In the majority of cases, increasing the moisture of the materials in the wall occurs as a result of its improper construction and the disturbance of the temperature regime. In this connection it is necessary to avoid the possibility of getting materials wet

which are in the wall structure and also to use materials with minimum moisture content.

The wetting of the wall structure takes place primarily through the absorbtion of water from moist air. The molecules of water vapor, which are in the moist air, come into the sphere of influence of the molecular forces of the dry material, precipitate on the surfaces of its grains or pores to form a layer of gas or liquid. This phenomenon is called sorption.

The wetting of the walls of buildings that are in use takes place in winter, when they separate two areas of air with different temperatures and as a rule with different water vapor tangents at equal barometric pressures. As a result of the difference in the water vapor tension on the two sides of the boundary, the water vapor moves from the area with the greater elasticity to the area with the lower value, in other words from the inner surface of the wall to the outer surface. In construction thermophysics, this phenomenon is known as vapor penetration, which involves the phenomenon of the moisture being both in a vapor and liquid form.

The amount of moisture which is absorbed in the wall is a function of the temperature of the vapor and its pressure in each layer of the structure. Since the vapor pressure and its temperature differ as a function of the thickness of the wall, the amount of vapor which is absorbed in each cross-section will differ. Cross-sections in the wall, in which the water vapor tension reaches its maximum values at corresponding temperatures, form a condensation zone.

The humidity regime has an extremely important sanitation and hygienic significance, since moist building material is a favorable medium for the development of fungi, molds and various biological processes that cause unsanitary conditions in residences. It also has a considerable influence upon the life of building; the greater the humidity of the building materials, the less resistance they have to frost and therefore will be subjected to a greater amount of cracking.

The moisture regime of buildings in use is characterized by the absolute humidity of the inside air being greater than the absolute humidity of the outside air, due to the presence of sources from which moisture is given off. These sources include: the preparation of food, the washing and drying of laundry, washing floors, using bath tubs, house plants, heaters and lights with exposed flames, etc. People also give off moisture - from 40 to 70 g/hour when at rest or working quietly. The absolute humidity of the inside air also depends upon the number of times the air is changed in the room; in winter, the influx of fresh air decreases the absolute and relative humidity.

Therefore, when designing a ventilation system for buildings that must operate all of the time it is necessary to pay particular attention to problems relating to the humidity situation.

Materials can be characterized as drying rapidly or slowly. The time it takes for them to dry naturally and the level of normal humidity depend not only upon the temperature of the air and its variations but also on the characteristic dimensions of the structure which is drying out - the length of the path along which the moisture must move in order to reach the evaporation surface.

The accumulation of moisture in the outside walls of buildings during one year of use is not allowed, and an increase in the humidity of structural materials during the cold season of the year must not exceed certain limits (SNIP II-A.7-71).

The analogy with the resistance to heat transmission, the concept of resistance to vapor penetration of a separate layer of material has been determined (in m^2/mm hg/hour/year), using the formula

$$R_{\text{п}} = \delta/\mu, \tag{14}$$

where μ is the coefficient of vapor permeability of the material, adopted in accordance with SNIP II-A.7-71, g/m/hour/mm hg.

The total resistance which is exhibited by a wall to a flow of water vapor diffusing through it is

$$\sum R_{\text{о.п}} = R_{\text{в.п}} + R_{\text{п1}} + R_{\text{п2}} + \dots + R_{\text{пn}} + R_{\text{н.п}}, \tag{15}$$

where $R_{\text{в.п}}$ and $R_{\text{н.п}}$ are the resistance to the moisture exchange on the inner and outer surfaces of the wall, m^2/mm hg/ hour/year;

$R_{\text{п1}}$, $R_{\text{п2}}$,... $R_{\text{пn}}$ is the resistance to moisture exchange of individual structural layers of a wall, m^2/mm hg/hour/year.

In multilayered structures, calculations will easily show the most advantageous (in the sense of preventing condensation) location for the structural layers with different degrees of permeability. The most widespread approach is the grapho-analytical method of calculation at a given flux of water vapor proposed by O.Ye. Vlasov and K.F. Fokin [2,9]. This method consists in the following:

1) On the cross section of a wall, a line is plotted showing the distribution of the temperature within the structure;

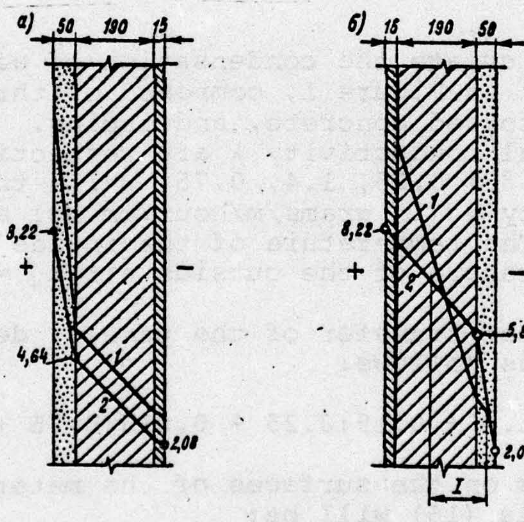
the temperature of the outside air (in this case, if we are determining the accumulation of condensing moisture inside the structure in winter or its evaporation during the warmer period of the year) we assume that the average temperature of the corresponding period of the year is equal. To plot the curve showing the distribution of the temperatures, we use the formula

$$\tau_n = t_в - [(t_в - t_н)/R_0](R_в + \sum_{n-1} R), \tag{16}$$

where $\sum n-1R$ is the total of the thermal resistances of the structural layers that are located between the inner surface and the plane in question within the structure, for which the temperature has been calculated.

2. Then we plot a line for the saturated partial pressures of water vapor E (Figure 1), corresponding to the plotted distribution of temperature within the wall. The values for these vapor pressures for temperatures in concrete cross sections of structures are shown in Appendix 1.

Figure 1. Wall Panels
a- with structural layer of dense material on the building side;
b - made of porous materials on the inside and with the outside structural layers made of dense materials: I - zone of possible condensation; 1 - maximum vapor elasticity; 2- actual vapor elasticity.



3. The curve showing the decrease in the actual values of the partial pressures of water vapor e is plotted within the limiting structure. If the line e lies below the line of saturated partial pressures E, the condensation of the diffusing water vapor within the structure cannot occur; the intersection of these two lines indicates the possibility of

such condensation, however (Figure 1b).

The slope of the curve showing the decrease in the actual pressures of water vapor depends upon the value of the resistance to vapor penetration of the individual structural layers. The values for the partial pressures at the interfaces between the individual layers are calculated by the following formula

$$e_n = e_в - (\Delta e / R_{о.п})(R_{в.п} + \Sigma_{n-1} R_п), \tag{17}$$

where $e_в$ is the partial pressure of the water vapor in the air of the room, mm Hg;

Δe is the pressure difference between the water vapor in the inside air and the outside air, mm Hg;

$R_{о.п.}$ is the total resistance of the surrounding structure to vapor penetration, m^2.hours.mm Hg/gram;

$\Sigma_{n-1} R_п$ is the total resistance to vapor penetration of the inside structural walls, located between the air of the room and the plane in which the value of the partial pressure is calculated, mm Hg x m^2 x hours/gram.

A considerable decrease in the partial pressures e in the interior structural walls of the boundary structure will occur in cases when these layers are made of dense materials or parts.

Example: Let us calculate the condensation of water vapor in a wall panels shown in Figure 1, composed of three layers: foam concrete, reinforced concrete, and facing. The coefficients of thermal conductivity λ are respectively equal to (in kcal/m.hours.°C) 0.25, 1.4, 0.75, while the coefficients of vapor permeability μ (in grams/m/hour/mm Hg) are 0.027, 0.004 and 0.013. The temperature of the inside air $t_в$ = 18°C, and the temperature of the outside air $t_н$ = -7°C.

The resistance to heat transfer of the panels determined by Formula (3a) is as follows:

R_o = 0,133 + 0.05: 1.4 + 0.19:0.25 + 0.015:0.75 + 0.05 = $1 m^2$.hours.°C/kCal,

and the temperatures on the surfaces of the material layers, calculated by formula (16) will be:

= 18 - 0.133[18-(-7):1] = 14.7°C
= 18 -25(0.133 + 0.035) = 13.8°C
= 18 - 25(0.133 + 0.035 + 0.76) = 5.2°C
= 18 - 25(0.133 +0.035 + 0.76 + 0.02) = 5.7°C.

The resistances to vapor penetration of the individual layers of the structure, determined by Formula (14), are as follows:

For reinforced concrete

$$R_{\Pi} = 0.05;0.004 = 12.5 \text{ m}^2\text{.hours. mm Hg/gram;}$$

For foam concrete

$$R_{\Pi} = 0.19:0.027 = 7.05 \text{ m}^2\text{.hours. mm Hg/gram;}$$

For the facing layer

$$R_{\Pi} = 0.015:0.013 = 1.15 \text{ m}^2\text{.hours. mm Hg/grams.}$$

The resistance to vapor penetration of the boundaries is calculated by Formula (15)

$\Sigma R_{o.\Pi} = 0.2 + 12.5 + 7.05 + 1.15 + 0.1 = 21$ mm Hg.m^2.hours/gram, where 0.2 is the resistance to moisture exchange on the internal surface and 0.1 is the resistance to vapor exchange on the outside surface of the boundary.

Let us determine the partial pressures of water vapor for the inside air e_B and outside air e_H, using expression 1:

$$e_B = 15.48 \cdot 0.55 = 8.53 \text{ mm Hg}$$

where 15.48 is the saturating partial pressure with $t_B = +18°C$ $\phi = 0{,}55$ is the relative humidity of the air in the room.

$$e_H = 2.53 \cdot 0.8 = 2.02 \text{ mm Hg,}$$

where 2.53 is the saturating partial pressure at $t_H = -7°C$; $\phi = 0.8$ is the relative humidity of the outside air. The partial pressure of the water vapor is calculated by Formula (17): on the inner surface of the wall:

$$e_1 = 8.53 -[(8.53-2.02):21] \cdot 0.2 = 8.22 \text{ mm Hg;}$$

on the inside surface of the foamed concrete:

$$e_2 = 8.53 = [(8.53-2.02):21](12.5 + 0.2) = 4.64 \text{ mm Hg;}$$

where 12.5 is the resistance to vapor penetration of the reinforced concrete layer; on the inside surface of a facing layer:

$$e_2 = 8.53 = [(8.53-2.02):21](0.2+12.5+7.05) = 2.47 \text{ mm Hg,}$$

where 7.05 is the resistance to vapor penetration of foamed concrete;

On the outside surface of the wall:

$$e_{H.\Pi.} = 8.53 = [(8.53-2.02):21](0.2+12.5+7.05+1.15) = 2.08 \text{ mm Hg.}$$

In the drawing (Figure 1), using the scale which we have adopted, we have plotted the values for the actual partial pressures e and the values for the maximum pressures E for the values of temperature calculated above on the surfaces of the layers:

τ, °C	$\tau_в = 14{,}7$	$\tau_1 = 13{,}8$	$\tau_2 = -5{,}2$	$\tau_н = -5{,}7$
E, mm Hg	12,54	11,28	2,93	2,83

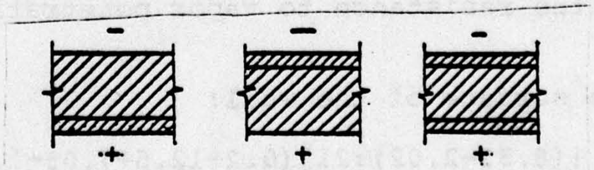
Plotting the lines e and E along the points plotted in the drawing (Figure 1a) indicates that line e does not intersect line E and consequently condensation of water vapor within the wall cannot occur. However, if the design in question is assumed to be such that the tracing is on the inside, in the room, and the reinforced concrete shell is on the outside (Figure 1b) and we carry out a similar calculation, we will find that line e intersects line E. Zone I, which is delimited by the points of intersection, is the zone of possible condensation of water vapor.

It follows from the above example that with a dense outside layer we can anticipate condensation of moisture in the outer part of the structure beneath this layer. Therefore, the course of the moistening process must be viewed on the basis of conditions of structural solutions to the boundaries - differences in the manner in which the materials are located in them.

1. When warming (and therefore, vapor permeable materials) are located in a colder (outside) situation, and the supporting (and less vapor-permeable) materials are located in warm and moist air (Figure 2a), access of water vapor from the rooms into the structure is made more difficult and the escape to the outside is made easier. Porous layers are heated on the room side almost without any vapor entering from the latter and dry out, even if damp material was used in the construction.

2. When the warming porous and supporting dense materials are installed in reverse order (Figure 2b), the structure is subjected to the active influence of vapor, but does not promote free escape of the vapor to the outside.

Figure 2. Diagram of Arrangement of Materials in a Wall.



a - warming materials on the outside of the structure; b - ditto, on the inside; c - ditto, inside the structure between the dense shells.

3. To improve the second, obviously unsatisfactory arrangement, a third solution has been adopted in a number of cases (Figure 2 c), in which the outside dense layer which impedes the escape of vapor from the structure is duplicated on the inside, for the purpose of preventing the penetration of moisture from the building into the wall. However, the practical use of this version is complicated by the fact that it requires using only completely dry materials for filler between the dense layers of the structure and it is only possible to use it during the dry season of the year since the engineering and construction moisture, which is introduced into the wall and is actually sealed up in it, cannot evaporate during the construction process.

This makes it necessary to construct vapor insulation on the room side which is as strong as and even stronger than the one provided on the outside, since the change in water vapor elasticity is always greater in vapor insulation which is located on the warm side than on the colder side. This means that when the inside and outside vapor insulation are of the same quality, the wall will be moistened slightly by the flow of the water vapor from the room. The vapor insulation which is located on the warm side does not fully protect the building against the penetration of water vapor during one season but creates an obstacle to its escape during the next season, when the temperature difference is reversed.

As far as the moisture conditions under the most severe conditions are concerned, combined roofs (without attics) are used. The presence of a water-insulating cover, which is practically completely impermeable to moisture, creates conditions for the intensive accumulation of moisture, particularly under the conditions of a harsh climate with a long winter. During summer, evaporation of the moisture from the structure takes place only toward the room. The brevity of the summer period does not allow long-term elimination of moisture from structures. Therefore the construction of unventilated combination roofs must be viewed as unacceptable. Only ventilated roofs, with continuous open air spaces, can be used on a practical basis.

The problem of constructing buildings under conditions which will ensure normal moisture conditions involves providing a free escape of the moisture to the outside when the moisture has entered the room from the walls. The danger of failing to observe this rule becomes apparent when the inner and outer separating layers are applied, since the builders and engineers often try to make a denser outside covering which will be subject to the effects of the outside atmosphere with precipitation, frost and wind. With the dense material of the walls and the relatively low moisture content of the air in the room, this will not be very harmful, since the amount of

water vapor that penetrates the solid mass from the room is insignificant.

In the case of porous materials or when the air in the room has a considerable relative humidity, this solution is dangerous due to the difference in densities of the separating layers. Therefore, as a way to prevent problems, as we mentioned earlier, it is necessary to reverse the situation - increase the density of the inside coverings relative to the outside ones in buildings which are heated.

It often happens that in multilayer walls, for structural reasons, it is necessary to apply porous heat insulating materials on the inside wall of a dense supporting structure. Thus, when the reinforced concrete spacial structures are heated, the heat insulating materials (especially the cellular plastics, polystyrene foam and phenolic resin) are applied or shaped around the bottoms of the supporting structures so as to use the work of the reinforced concrete to the best and to exploit its water insulating properties. It is necessary to provide the necessary vapor insulation for the structure on the room side in order to protect the building against moisture.

When using walls made of highly porous sectional parts and concrete, it is important to keep in mind that their normal thermal efficiency can only be ensured by sealing up the spaces and capillaries on both surfaces, so that in this case it will be denser on the inside than on the outside.

Inside any limiting structure, made of porous air-dry materials, it is easy to create a zone (or rather a plane) in which the development of condensation of diffusing water vapor is most probable and will occur before it does in other sections. In laminated structures, this dangerous cross section will be the plane of contact between comparatively permeable materials (friable, porous, etc.) to the denser layers which are located on the outside, colder parts of the structure.

In the design of walls which are warmed on the inside, this will be the plane of contact between the heater and the denser parts; when the walls are heated on the outside, the dangerous cross-section will be beneath the outside facing layer; in coverings with multilayer roll coverings for the roof, the dangerous zone is the layer beneath the roof. In the structures of homogeneous walls of buildings with moisture which is not above normal, the zone of maximum moisture is located approximately two-thirds of the way from the inside surface, since the moisture of the material in this zone is low.

When moisture condensation takes place, the partial pressure in the dangerous cross-section of the structure is equal to the saturated pressure E_{ω}. The potential for vapor transfer,

which causes the moisture, is the difference $e_{B} - E_{\omega}$, and causes drying $E_{\omega} - e_{H}$. In order to prevent moisture from accumulating in the structure of the wall, it is important to ensure that the following relationship exists:

$$(E_{\omega} - e_{н})/(e_{в} - E_{\omega}) = R'_{н.п}/R'_{в.п} = \beta. \qquad (18)$$

In the case of walls of heated rooms with normal humidity β must not exceed 0.33 while in the case of moist environments it must be no more than 0.2.

For certain values of β the ratio of the total amount of water vapor diffusing through the internal part of the structure, P_{diff} to the amount of water vapor which is contained in the moist zone, $P_{y\text{вл}}$, may be expressed by the coefficient of the moisture conditions $\bar{n}$, whose value changes as a function of the ratio of the resistances to vapor penetration:

$$\bar{n} = P_{диф}/P_{увл} = P_{диф}/(P_{диф} - P_{осуш}) = \\ = 1/R'_{в.п} : (1/R'_{в.п} - \beta/R'_{н.п}). \qquad (18a)$$

The value of the coefficient of the humidity conditions can vary from $\bar{n} = 1$ for walls with impermeable outside areas, when all of the water vapor diffusing through the internal part of the structure is consumed in moistening the wall to $\bar{n} = 10$ for structures with a permeable outside layer, when an insignificant portion of the diffusing vapor is consumed in moistening the wall.

In the case of highly permeable outside areas, for example when there is a layer which is ventilated by the air beneath the outside protective layer, the value of $\bar{n}$ becomes equal to infinity, indicating the impossibility of accumulation of moisture through diffusion. In these situations, there is no need to calculate the moistening of the structure by the diffusion vapor. In such structures, there is no need for vapor insulation or to check the adequacy of the resistance to vapor penetration in the interior portion (Table 1).

The time Z, expressed in hours after whose elapse condensation of water vapor can occur in the dangerous cross section of the structure, is determined by the formula

$$Z = K_0 \bar{n} \delta_{\omega} \gamma \xi R'_{в.п}/(e_{в.п} - E_{\omega}). \qquad (19)$$

where K_o is the coefficient which is used for dry conditions, 0.006; for normal it is 0.005 and for wet - 0.004;

δ_{ω} is the thickness of the internal layer of the structure up to the condensation plane, m;

Table 1. Values of $\bar{n}$ as a Function of $R'_{H.\Pi.}/R'_{B.\Pi.}$ and the Moisture Regime of the Structure

Structures	τ_ω °C	Moisture conditions of the room	$R'_{H.\Pi.}/R'_{B.\Pi.}$ 0.25	0.37	0.5	1	2	5	10
Roofs and walls, protected on the outside by a dense protective layer	-5	Normal (9 mm Hg)	-	10.0	3.0	1.50	1.20	1.07	1.04
		Wet (13 mm Hg)	5	2.2	1.67	1.25	1.12	1.05	1.02
Walls homogeneous or heated on the inside	+3	Normal	-	-	-	-	-	1.67	1.25
		Wet	-	-	-	-	-	1.25	1.10

Note: τ_ω = average rough temperature in the condensation zone.

γ - the specific gravity of the material, kg/cm;

ξ - relative vapor capacity of the structural material, determined on the basis of the isotherm of sorption of the material, g/kg;

$R'_{B.\Pi.}$ - resistance to vapor penetration of the interior layer along the condensation plane, mm Hg·m²·hours/grams;

$e_{B.\Pi.}$ - partial pressure of vapor at the surface of the structure, facing the room, mm Hg;

E_ω - saturation pressure of water vapor in the condensation zone with a temperature in the zone of τ_ω, mm Hg.

The resistance to vapor penetration of the inner part of the structure, required to ensure that there is no prolonged condensation of moisture in the dangerous cross-section, is determined by the formula

$$R'_{B.\Pi} = (e_{B.\Pi} - E_\omega)\, Z / K_0 \delta_\omega \gamma \xi \bar{n}. \quad (20)$$

Example 1. Determine the length of time required for the maximum permissible moistening of the combination (attic-less) roof made of reinforced concrete panels 0.12 m thick with a specific gravity of 750 kg/cm.

The partial pressure of the water vapor at the surface which faces into the room, $e_{B.\Pi.}$, = 9. mm Hg, E_ω = 4.22 mm Hg. The

roof has a three-layer covering - rubberoid between two layers of pergamin, with a resistance to vapor penetration $R_{\pi} =$ 18.6 mm Hg·m^2·hours/grams. The relative vapor capacity of foam concrete ξ from 60 to 100% along the sorption isotherm is 201 grams/kg. The resistance to vapor penetration of the inner part of the structure up to the plane of probable condensation in the layer beneath the roof is 6.9 mm Hg·m^2·hours/gram. The ratio of the resistances of the outer and inner parts of the structure $R'_{H.T.}/R'_{B.\Pi.} = 18.6/6.9 = 2.7$, the coefficient n for conditions of moisture according to Table 1 is 1.16. The length of time required for maximum permissible moistening according to formula (19) is

$$Z = 0.005 \cdot 1.16 \cdot 0.12 \cdot 750 \cdot 201 \cdot 6.9 : (9 - 4.22) = 150 \text{ days approx. 5 months}$$

which is in excess of the time required for diffusion, which is about 4 months.

It follows from this computation that the use of reinforced foam concrete coverings under these conditions is possible without instaling any kind of special vapor-insulating layers.

Example 2. It is necessary to determine the kind of vapor insulation to be used for an attic-less roof for a building in Chelyabinsk with $t_B = +24°C$; $\phi_B = 60\%$, $e_{B.T.} = 13$ mm Hg.

The structure of the roof was made in the form of a combination reinforced concrete pannel 0.03 m thick, $\mu = 0.004$, covered with a foam concrete layer 0.2 m thick with a specific gravity of 500 kg per cm and a coefficient $\mu = 0.026$ gram/m·hour·mm Hg and a relative vapor capacity $\xi = 145$ gram/kg, covered with three layers of tar paper, $R_{\text{ц}} = 18.3$ mm Hg·m^2·hours/gram.

Assuming that the vapor insulation in the form of one layer of rubberoid attached to the bituminous mastic, $R_{\text{ц}} = 8.3+2 =$ $= 10.3$ mm Hg·m^2·hour/gram, we determine the resistance to vapor penetration of the inner part of the structure:

$$R'_{B.\Pi.} = 0.2 + 10.3 \cdot 0.03 : 0.004 + 0.2 : 0.026 = 25.7 \text{ mm Hg·cm·hour/gram.}$$

The ratio of the resistances of the vapor penetration of the outer and inner parts of the structure is 18.3:25.7 = 0.7, so that by determining the coefficient of the conditions of moisture according to Table 1 for moist environments, we have $\bar{n} = 1.5$.

The required resistance to vapor penetration of the inner part is calculated by Formula (2). The value of Z for the case in question, calculated by expression (19) is 168 days.

$$R_{\Pi}^{TP} = (13-2.1) \cdot 168 : (0.004 \cdot 0.2 \cdot 50) \cdot 145 \cdot 1.5) = 21.1 < 26 \text{ mm Hg·m}^2\text{·hour/gram}$$

Consequently, the vapor insulation which has been adopted meets the requirements for limiting the moisture of the building.

For modern structures with laminated panelled walls vapor insulation may be required only in cases when walls made of very brittle heat-insulating materials are heated, with a limited vapor capacity. When using cellular concrete to heat the panels no special vapor insulation is required.

Example 3. It is necessary to determine whether a special vapor insulation will be required for the panelled wall of a residence protected on the outside with a reinforced concrete facing: $\delta = 0.025$ m, $\mu = 0.004$ gram/m·hour·mm Hg, and with foamed concrete heated on the inside: $\delta = 0.015$ m, $\gamma = 660$ kg/m^3, $\mu = 0.023$ gram/m·hour·mm Hg, $\xi = 163$ grams/kg with a facing layer; $\delta = 0.015$ m, $\mu = 0.015$ gram/m·hour·mm Hg. The resistance to vapor penetration of the inner part of the wall is

$$R'_{\text{в.п.}} = 0.2 + 0.015:0.015 + 0.15:0.023 = 7.8 \text{ mm Hg} \cdot \text{m}^2\cdot\text{hour/gram},$$

and for the outer part

$$R'_{\text{н.п.}} = 0.025:0.004 + 0.1 = 6.35 \text{ mm Hg}\cdot\text{m}^2\cdot\text{hour/gram},$$

while with $R'_{\text{в.п.}} : R'_{\text{н.п.}} = 6.35:7.8 = 0.81$ $\Pi = 2.2$

The required resistance to vapor penetration of the inner part of the panel in a room with normal humidity is:

$$R^{\text{тр}}_{\text{п}} = (9-3)\cdot 152:(0.005\cdot 0.15\cdot 600\cdot 163\cdot 2.2) = 5.65 < 7.8 \text{ mm Hg}\cdot\text{m}^2\cdot\text{hour/gram}.$$

Consequently, no special vapor insulation is required for this type of panel construction.

EFFECT OF SNOW AND RAIN ON BUILDINGS

The outside walls of buildings are wet by rain driven by the wind, which conveys the moisture onto the vertical surfaces. As a result, there is saturation with atmospheric humidity which leads to deterioration of the qualities of the wall. The degree to which they are wet is a function of the amount of rainy weather, the size of the drops of rain that fall, and the direction in which they move in the outside air.

The physical aspects of the wetting of outside walls by rain may be expressed as follows: a very fine drop of water, striking the surface of a building made of a dense material without any pores, retains the energy required for the moisture to adhere to the material. The energy level is a function of the properties of the surface; in the case of structures

that are easily wet by moisture, it is greater, and decreases when materials which are difficult to wet are used or when the surface of the structure is treated in a special way. Under the influence of gravity, the drops slide down the surface of the building. A state of equilibrium arises when the adhesive energy and the force of gravity are the same. The effect of the force of gravity is a function of the mass of the drop and the slope of the surface of the building. Fine droplets will even adhere to a vertical surface; penetrating into the structure, they increase the level of its wetness and thereby increase the danger of damage.

When strong, brief rains alternate with clear hot weather, most of the moisture which is soaked up by the outside surface of a structure evaporates rapidly. This means that the wetting is of a temporary nature, without the moisture penetrating deeply into the building. When the rain is in the form of a drizzle, with very fine droplets, deposited under conditions of considerable cloudiness and a high relative humidity of the ambient air, with no alternation with clear warm weather, the nature of the wetting of the structure is completely different. In this case, all of the small raindrops that strike the outside of the wall remain on it and are soaked up by porous materials, and there is practically no evaporation of the moisture. A considerable part of it penetrates into the structure. Even greater wetting takes place when there are prolonged heavy rains, usually accompanied by wind, increasing the amount of moisture which is conveyed against the surface of the wall.

It is usually undesirable to have the walls wet by rainfall in those climatic regions where the evaporation of moisture is impeded by the high relative humidity of the ambient air (humid regions, as they are referred to on the basis of their climatic characteristics).

It is very important for water to be carried off the roofs of buildings correctly and promptly, since during heavy rainfall the amount of precipitation which can be carried away from the surface of a building may be very significant. Therefore, when the water is allowed to run freely off the roof when the latter is protected, as it is in many cases, there is an intensified wetting of the outer walls and their parts - balconies, peaks, plinth courses, which come in contact with the water running off the roof. At a wind velocity of 2 m/sec., rain water will be carried from the edges of the roof against the walls of a building.

The wetting of the walls by precipitation freely flowing off the roof is largely a function of the overhang or edge of the roof. It has been found that extending the eaves even 50 cm fails to protect a building against precipitation striking its outer elements. Under extremely unfavorable

conditions, balconies may be located directly beneath the eaves.

On the north-eastern coast of the USSR, weather conditions are such that the outside surfaces of the vertical walls of buildings are exposed to conditions in which they are wetted constantly by atmospheric humidity. The duration of the continuous rainfall is 8-10 hours for each month of the warm season of the year. (The period with the positive average monthly temperatures of the air).

The average monthly amount of precipitation falling under the influence of the wind against the walls of a building which face into the wind is in excess of 100 mm in certain areas. In certain cases, there is an extreme wetting of the walls of the buildings by atmospheric precipitation in coastal areas, in Chukotka and the Taymyr, for example.

In all kinds of roofs on heated buildings, snow will thaw not only when the temperature of the outside air is positive, but even when it is negative. There is a certain relationship between the thickness of the snow cover at the beginning of thawing and the temperature of the outside air for different heat-protective characteristics of the roof. In the case of combination roofs the snow begins to melt when the outside air temperature is -10° or more.

The system of outside gutters made of sheet metal, as well as the eaves and the roof itself, under the influence of alternating freezing and thawing, rapidly become useless and require frequent repair. The principal reason for this is the formation of ice crusts and ice plugs, which develop under the influence of inhomogeneous distribution of temperature over the surface of the roof. At the beginning of thawing of the snow, the melt water which is produced runs down the roof, entering areas where the internal heat is much less effective.

Therefore, some of the water at these negative temperatures will freeze, plugging up the gutters and drains, and the part which continues to run down the slope of the roof will flow over the edges of the gutters, forming ice crusts and icicles. When the temperature drops, the thawed zone becomes smaller, thawing gradually ceases, and the zone of ice formation expands. If the temperature drops further, thawing ceases entirely.

When the temperature rises to 0°C or above thawing in the warmest part of the roof starts up again, and the formation of ice crusts continues in the colder areas. This is due to the higher thermal capacity of the roof in the area where the roof is near the wall and where it is heated much more slowly that it is in other areas. The melt water which is

formed when the snow melts and cannot escape from the roof increases the load of ice when the temperature falls again.

The flat reinforced concrete roofs that are used, with slopes of 0.05 and not protected by parapets, edges or other structures, have the snow removed from them under the infuluence of the wind. While ice and icicles form on the edges and projecting parts of buildings with sloping roofs, almost none will be found on the edges of flat roofs. It has been determined that flat roofs lose their snow cover at wind speeds of about 4 m/sec.

CHAPTER II SANITARY-HYGIENIC REQUIREMENTS IN BUILDING DESIGN

HUMAN HEAT EXCHANGE IN CLOSED ROOMS

The principal purpose of buildings is to protect man against external climatic conditions. It is necessary not only to protect people against unfavorable natural influences but also to create optimal microclimatic conditions in their living environment. In the opinion of hygienists, the most comfortable conditions are those in which the thermoregulatory system of the organism is in a condition of minimum stress (or physiological rest), and all of the other physiological functions take place at a level which is most favorable for rest and for the recovery of the energies of the organism following working stress.

In the human organism, as the result of biochemical processes, thermal energy is constantly being formed, which is partially consumed in metabolic processes and partially is given off in the form of heat into the surrounding environment. Human heat exchange with the surrounding environment primarily is the result of an exchange of heat by radiation, convection and evaporation and is a function of the physiological activity of man and the microclimatic parameters of the surrounding environment.

Insufficient heat loss is a reason for deterioration of the general feeling of an individual, and a decrease in his working capacity, both mental and physical,and can sometimes lead to heat stroke and even death. However, in the case of excessive heat loss, the organism is excessively cooled, disrupting its normal vital activity and often leading to colds.

Heat exchange between man and his environment obeys the general laws of heat transmission and is governed by the following formulas:

For radiant heat exchange

$$Q_{\Lambda} = a_{\Lambda} F_{\Lambda} (\tau_{ч} - t_{\rho}), \tag{21}$$

where α_{Λ} is the coefficient of radiant heat exchange, kcal/m^2·hour·°C

F_{Λ} is the surface of an individual which participates in heat exchange through radiation, m^2;

$\tau_{ч}$ is the average surface temperature of a clothed individual, °C;

t_{ρ} is the average radiation temperature of a room, °C;

with a convective heat exchange

$$Q_к = \alpha_к F_к (\tau_ч - t_в), \tag{22}$$

where α_K is the coefficient of convective heat exchange, kcal/m^2·hours·°C;

F_K is the surface of an individual participating in heat exchange through convection, m^2;

t_B is the air temperature in the room, °C;

with heat loss by evaporation

$$Q_H = rq/1000 \tag{23}$$

where r is the latent heat of evaporation, kcal/kg;
q is the amount of moisture given off by an individual, grams/hour.

For normal vital activity of man, it is insufficient to observe proper heat balance between the organism and the surrounding environment, it is also necessary to maintain a certain thermal condition of the individual parts of the body. The ratios of the amounts of heat lost by an individual through radiation, convection and evaporation must be in certain proportions with the permissible limits for deviation, which are provided for by the thermal regulatory system of the organism. Human heat exchange depends upon the microclimate of the room: temperature, humidity and movement of the air, as well as the temperature of surrounding surfaces.

Particular attention should be paid in this respect to the regions of the Far North, with a harsh climate, different working conditions and living conditions of the native population, as well as the mastery of these regions by those who come from the central and southern parts of the country pose certain difficulties for the microclimate of residences, taking into account the ethnographic and demographic features of various population centers.

In the people of different nationalities, we can find importand differences in their requirements for the air temperature in houses, even in a given climatic region. They depend upon the type of house, the heating and ventilating equipment, the type of work done, clothing, and many other factors which govern the nature of life.

The native population in the northern regions, living in well built apartment houses of modern design, suffer from a shortage of fresh air and at temperatures of 18-20°C they feel "hot"

and "fatigued". Even children who are raised in nurseries have a hard time getting used to temperatures above 18°C.

The immigrant population, under the same microclimatic and living conditions which exist in buildings in the north, suffers discomfort which is reflected in their feelings and in their health. The reason for this is that with a sharp change in the natural and climatic conditions, affecting the individual (low temperatures, strong wind), there is an inhibition of the internal processes of vital activity in the organism with a considerable stress on the thermal regulatory mechanisms. The complicated process of physiological adaptation of the organism to the surrounding environment under the new conditions and its duration depend primarily upon the internal microclimate of the buildings which must promote rapid acclimatization, i.e., normalization of the thermal conditions of the individual and recovery of his lost activity.

OPTIMUM PARAMETERS FOR THE MICROCLIMATE OF RESIDENCES

Air Temperature in Buildings

The most important parameter in the environment surrounding man is air temperature. It has been found that individuals who live in different climatic regions determine their requirements for a comfortable temperature of a building in different ways. Nevertheless, there is a general tendency that can be seen - the more harsh the outside climatic conditions are, the higher the requirements for the air temperature in the room. This is because in warm regions the human organism does not suffer as severe cooling in the open air as it does in the cold northern regions, where, under the conditions of a harsh winter, even a brief stay in the open air subjects the individual to the severe effects of low temperature. Therefore, for rapid normalization of the thermal conditions of the individual in a building it is necessary to have a high temperature.

However, a moderate increase in air temperature in a building leads to a disproportion of the heat balance in man due to a disruption of the value of its individual components. As the air temperature rises, the convective heat loss decreases and there is an increase in the heat loss by radiation and evaporation. The limit for permissible variations in temperature from the value at which comfortable heat conditions in a room are observed decreases.

As a result of numerous investigations, it is recommended that the following temperatures be maintained for the inside air in buildings during winter: in northern regions - 21-22°C, in moderate climates 18-20°C, and in southern latitudes 17-18°C. However, these standards assume that the calculated temperature of the inside air is 18°C for the moderate zone and 20°C for northern regions.

Another item which is very important from the hygienic standpoint is the magnitude of the air temperature changes along the horizontal and with height of a building. It is recommended that the temperature gradients along the horizontal not exceed 2°C and 2-3°C in the vertical. It is considered that under these conditions a normally dressed individual at a state of rest will not perceive the temperature inhomogeneties. Increasing the vertical temperature differential usually is associated with a sharp drop of temperature in the lower part of the building, leading to a general cooling of the organism, especially the feet. Studies have shown that even at comparatively small deviations from the zone of thermal comfort, vascular reactions occur primarily in the extremities, leading to a disruption of the physiological equilibrium of the entire organism.

The greatest temperature changes with height of residences are observed in northern regions at low temperatures of the outside air, especially in apartments on the second floor when there is a breezeway beneath the floor of their appartments. The effort to achieve a comfortable heat regime in buildings by increasing the air temperature does not yield positive results, since it leads to even greater changes with increasing building height.

Another area which requires attention as far as the heat conditions of residences is concerned is the temperature variations in the interior air which take place due to the effect of changing temperatures of the outside air on the building and the insufficient adjustment to this effect of heat supply to the heating apparatus. Sharp changes in the air temperature of buildings lead to a disturbance of the thermal regulatory system in man, so that it rapidly becomes fatigued and the individual catches cold. Therefore, keeping air temperatures within the limits that will ensure temperature comfort for those living in a building is a necessary condition for the operation of residences.

Atmospheric Humidity

High atmospheric humidity, at both high and low temperatures, has an unfavorable affect upon human comfort. In cold moist air, man feels chilly, unpleasant; this is because there is an increase in heat loss from the organism because the moist air conducts heat better and can contain more heat. Clothing becomes wetter and therefore more heat conductive, therefore drawing off a great deal of heat from the body.

The increased air temperature robs the organism of the ability to give off significant amounts of heat, and very small drops of perspiration appear on the surface of the skin. They

evaporate and cool the body. Some of the heat developed by the organism is used up in evaporating the moisture from the surface of the skin, while the mechanism for heat loss through radiation and convection is less effective. If the relative humidity of the air is high, evaporation of perspiration is impeded, the skin becomes swollen, the pores open, and the individual becomes more sensitive to temperature variations; his overall temperature conditions deteriorates. If the air is relatively dry, the perspiration which is produced gradually evaporates, leading to an intensive cooling of the body. Low atmospheric humidity in turn is harmful to the mucous membranes of the eyes, nose, and throat, creating the unpleasant sensation of "dryness". In this case, even the filtration capacity of the mucous membranes of the upper respiratory pathways are impeded, so that they cannot trap the microflora and dust that are contained in the air.

Field studies of the environment as represented by the air in buildings in Far Northern regions show that the relative humidity of the inside air is often at a level of 20-25% relative to normal, and for residences it is often 30-60%. This is due to the small amount of moisture in the outside air that enters the buildings. Thus, at a temperature of -20°C, even with maximum saturation (corresponding to ω_H = = 100%) the amount of moisture contained in 1 cm of air is less than 1 gram, while at 20°C and a relative humidity of only 40% the moisture content in the same volume of air will be 7 grams. Residential humidifiers cannot produce enough moisture for the air in the rooms, because of the great difference in partial pressure of the inside and outside air; the moisture tries to penetrate the room through cracks and vapor-permeable walls.

In order to ensure normal microclimates in residences in the north during winter, artificial humidification of the air in the apartments is necessary for their use. The relative atmospheric humidity must not be less than 30%.

Mobility and Cleanliness of the Air

The rate at which air moves has a considerable influence upon the human organism. In quiet, stagnant air, inertia of human reactions develops with respect to thermal stimuli. Even at a comfortable air temperature, very low air movement causes a sensation of fatigue. The higher the air temperature, i.e., the smaller the temperature difference between the human body and the air, and the lower the rate at which the air is moving, the less heat the individual will lose through convection.

Increasing the rate at which the air moves increases convective heat loss, and a speed in excess of 0.2 m/second is perceived as uncomfortable, when the individual complains of a "draft."

In rooms with poor ventilation, when a great many people are present, the number of light ions decreases and the number of heavy ions increases. This is explained by the precipitation of electrically charged ions of air on dust particles and microbes, which are suspended in the air of the room. Since electrically charged dust particles, to a greater degree than neutral ones, are trapped in the upper respiratory pathways, the accumulation of heavy ions in poorly ventilated rooms is considered to be a factor which is unfavorable from the hygienic standpoint. Allowing fresh outside air to enter the room considerably improves the ionization situation in the room.

One of the parameters for the hygienic conditions of the environmental air, reflecting the degree of pollution of the air by the end products of vital processes and human vital activity, is the concentration of carbon dioxide. Man produces 20-30 liters of carbon dioxide per hour, but its principal source is the gas burners of kitchen stoves.

Since carbon dioxide is heavier than air, its greatest concentration will be found in the lower regions of residences, where children are to be found most of the time. Therefore, exchanging the air in buildings must be organized so that the concentration of carbon dioxide does not exceed 0.1%. Standards (SNiP II-G.7-62) have established that there should not be any less than 25-30 cm/hour of fresh air provided for each individual.

Hence, a certain degree of mobility of the air and superimposed air exchange in buildings are required both for temperature comfort and for getting rid of microflora, dust and toxic products. Optimum air mobility in the respiration zone at temperatures of 18-20°C and relative humidity of 40-50% is 0.05-0.07 m/second (not above 0.1 m per second). With these parameters, we can have optimum temperatures and humidities for the skin and the individual will have comfortable heat conditions.

Influence of Radiation Temperature on the Thermal Conditions in Man

In characterizing the thermal conditions of a room, we can speak of the temperature of the inside air in it. However, the temperature comfort for an individual who is in a room cannot be determined unambiguously by this parameter alone.

The principal heat losses of man (about 50% of total heat losses) occur through radiant heat exchange, depending on the temperature of the surrounding surfaces and the temperature difference between the wall and the air. Cold walls result in an intensification of heat radiation from the surface of the human body.

If the surface layer of the skin serves as a temperature regulator in convective cooling, not allowing negative temperatures to influence the organism, in radiant cooling there is a decrease in the temperature of the deeper tissues, with a longer recovery period and more significant functional changes in the organism.

An individual can distinguish between a heat source if the latter gives off 0.00015 calories per cm^2/second. At this level, however, the human organism is sensative to radiation cooling toward the relatively cold objects surrounding it and the walls of the room.

The critical characteristic of radiant heat exchange in man involving the surrounding medium is the average radiation temperature [see equation (21)], calculated by the following formula

$$t_p = \sqrt{\varepsilon_0 \sum T_i^4 \varepsilon_i \varphi_i + T_0^4 \left(1 - \varepsilon_0 \sum \varepsilon_i \varphi_i\right)} - 273, \qquad (24)$$

where are the temperature (in K) the blackness and angular coefficient of radiation of the internal surfaces of a room;

T_0, ε_0 is the temperature (in K) and the blackness of a body (human clothing) for which is determined.

For practical calculations in determining the weighted mean radiation temperature of a room with sufficient accuracy, we can use the simplified formula

$$t_p = \sum F_i t_i : \sum F_i, \qquad (25)$$

where F_i, t_i are the area (in m^2) and temperature (in °C) of the internal surfaces of a room.

The weighted mean radiation temperature of the room must have a strict relationship to the temperature of the inside air, and their combination should ensure temperature comfort in the room.

From equations (24) and (25) we can obtain the relationship between the average radiation temperature t_p and the temperature of the inside air t_B.

Assuming for the winter season [1] $\tau_H = 25°C$, $\alpha_K = 2$, $\alpha_Л = 4.4$ kcal/m^2·hour·°C, $F_k = 1.9$, $F = 1.7$ m^2, and the total radiant and convective heat exchange for man in a state of temperature comfort to be 75 kcal per hour, we find that

$$t_p = 27.7 - 0.507 t_B \, . \qquad (26)$$

The studies of N.K. Ponomareva [7] and M.S. Goromosov [3] of the combined influence of the average radiation temperature and the air temperature of the room on sensations in man led to the discovery of the zone of comfort combinations (Figure 3).

In calculating the resistance to heat transmission of outside walls, SNiP recommends a temperature difference Δt^H between the temperature of the inside air t_B and the temperature of the inside surface of the outside walls τ_B to be equal to 6°C for the walls of all residences. However, hygienists, on the basis of the temperature sensations observed in man for negative radiation on the surface of outside walls, point out that the temperature of the inside surfaces must not be below the temperature of the room air by more than 3°C. However, these temperature differences cannot have a strictly fixed value for all rooms, and must be calculated as a function of the ratio of the area of their outside (cold) and inside (warm) walls.

Let us use an example to study this situation. Table 2 shows four different rooms which have identical (from the structural standpoint) outside walls with temperature resistances that have been calculated using the method of SNiP II-A.7-71. The difference between the rooms consists in the different ratios of their inside (F_B) and outside (F_H) walls. With standardized values for $\Delta t^H = t_B - \tau_B$ the temperature on the inside surfaces on the outside walls (for calculated values of t_B and t_H) will be a constant regardless of the volume-planned solution for the room: for walls $t_B = 6°C$, ceiling $t_B = 4°C$ and floor $t_B = 2°C$.

The weighted mean radiation temperatures of the rooms, shown in the table, were calculated using Formula (24). If we plot on the comfort graph (Figure 3) the values of t_p for the rooms in question for an air temperature of 18°C, we can see that the temperature regime corresponds to discomfort conditions (in the zone of possible cooling I). When the temperature t_B rises to 20°C, only the third room corresponds to the conditions required for temperature comfort, while the first and second remain in the zone of possible body cooling I, and the fourth room the temperature conditions correspond to discomfort, in the overheating zone.

These data confirm that the temperature differences between the air and the surface walls cannot be constant values, and

must be determined for each individual room on the basis of conditions required to ensure temperature comfort for man.

Table 2. Weighted Mean Radiation Temperature of Rooms t_p

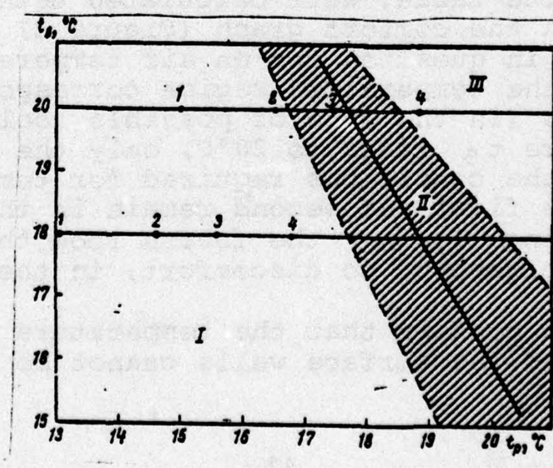
Characteristics of the room	t_B, °C	F_H, m²	F_B, m²	Outside wall	Inside wall	Floor	Ceiling	Window	t_p, °C
Corner room of an intermediate story (two windows)	18	24.3	60.3	$\frac{20.3}{12.0}$	$\frac{24.3}{18.0}$	$\frac{18}{15.5}$	$\frac{18}{18}$	$\frac{4}{8}$	15.6
	20	24.3	60.3	$\frac{20.3}{14.0}$	$\frac{24.3}{20.0}$	$\frac{18}{17.5}$	$\frac{18}{20}$	$\frac{4}{9}$	17.5
Corner room on upper floor (two windows)	18	42.3	42.3	$\frac{20.3}{12}$	$\frac{24.3}{18}$	$\frac{18}{15.5}$	$\frac{18}{13.5}$	$\frac{4}{8}$	14.6
	20	42.3	42.3	$\frac{20.3}{14}$	$\frac{24.3}{20}$	$\frac{18}{17.5}$	$\frac{18}{15.5}$	$\frac{4}{9}$	16.6
Movable house on skis (one window)	18	84.6	-	$\frac{46.6}{12}$	-	$\frac{18}{15.5}$	$\frac{18}{13.5}$	$\frac{2}{8}$	13
	20	84.6	-	$\frac{46.6}{14}$	-	$\frac{18}{17.5}$	$\frac{18}{15.5}$	$\frac{2}{9}$	15
Room on intermediate floor of multistory residence (one window)	18	8.1	76.5	$\frac{6.1}{12.0}$	$\frac{40.5}{18.0}$	$\frac{18.0}{15.5}$	$\frac{18}{18}$	$\frac{2}{8}$	16.8
	20	8.1	76.5	$\frac{6.1}{14.0}$	$\frac{40.5}{20.0}$	$\frac{18}{17.5}$	$\frac{18}{20}$	$\frac{2}{9}$	18.8

Note: 1. The dimensions of all these rooms are 6X3 m, with a height of 2.7 m.

2. In the numerator are the areas of the bordering structures (in m²) while the denominator shows the temperature on the inner surfaces.

Figure 3. Graph Showing the Radiation-Convective Comfort for Rooms.

I - Zone of possible body cooling; II - zone of comfortable heat conditions; III - zone of possible overheating of the body.



Thermotechnical Calculation of Outside Walls on the Basis of Conditions Required to Ensure Temperature Comfort for Man in Rooms

As we pointed out above, the temperature difference between the air in the room and the temperature on the surface of a wall must be determined from the condition of ensuring normal heat exchange for man with the surrounding environment. The value of the temperature differential Δt^{H} must be assumed to be equal to $t_{B} - \tau_{B\rho}$, where $\tau_{B\rho}$ is the calculated temperature on the inside surfaces of the outside walls, determined from the condition of ensuring temperature comfort for man in rooms. The value of $\tau_{B\rho}$ is determined by the formula

$$\tau_{B_p} = [t_p(F_H + F_B) - t_B F_B]/F_H. \tag{27}$$

Then Formula (1) becomes:

$$R_0^{TP} = (t_B - t_H)\,n/\alpha_B(t_B - \tau_{B_p}). \tag{28}$$

Taking into account the temperature variations of the air in rooms, the calculation of t_p must be carried out at the minimum permissable air temperature in the room, i.e., instead of t_B in Formula (26) we let $t_{B\,min} = t_B - \Delta t_B$, where Δt_B is the permissible variations in the temperature of the inside air in the room.

In the case where $\tau_{B\rho} < \tau_K$ (where τ_K is the temperature for condensation of moisture on the surface of the wall) in computation of Formula (28) we can use $\tau_{B\rho}$ instead of τ_K.

To determine the resistance of the floor to heat transfer, if $t_B - \tau_{B\rho} > 2°C$, it is necessary to have the temperature difference between the temperature of the inner air and the temperature of the inside surface of the floor be 2°C.

Example. Determine the required resistance to heat transmission of the outside walls of a house made of plastic (Figure 4), on the basis of the conditions for temperature comfort of man in buildings.

We can perform the calculation for a living area II (with a radiator-type electric heater). The proposed area for the use of this building is the settlement known as Palatka in the Magadan region. The wall panels of the house are made of an outside protective layer of fiberglas 4 mm thick, a heating layer made of polystyrene foam (specific gravity 40 kg/m^3) and an inside separating layer made of fiberboard panels 14 mm thick. Since the protective outside and inside layers were chosen for their structural properties, the calculation boils down to determining the thickness of

the layer of heat insulation.

The degree of solidity can be determined by the formula

$$D = \sum sR = s_{д.в}\delta_{д.в}/\lambda_{д.в} + s_{из}\delta_{из}/\lambda_{из} + s_{с.п}\delta_{с.п}/\lambda_{с.п}, \qquad (29)$$

where R is the resistance to heat transmission of the individual layers of the walls, $m^2 \cdot hour \times °C/kcal$;

s is the coefficient of heat absorption of the material of the corresponding layer, $kcal/m^2 \cdot hour \cdot °C$.

The subscripts in Equation (29) have the following meanings: "d.b." fiberboard layer, "iz" - heater; "s.p." fiberglas.

The values of λ (in $kcal/m \cdot hour \cdot °C$) and s (in $kcal/m^2 \cdot hour \cdot °C$) in these materials are as follows

For fiberglass $\lambda_{c.п.} = 0.65$; $s_{c.п.} = 9.2$;

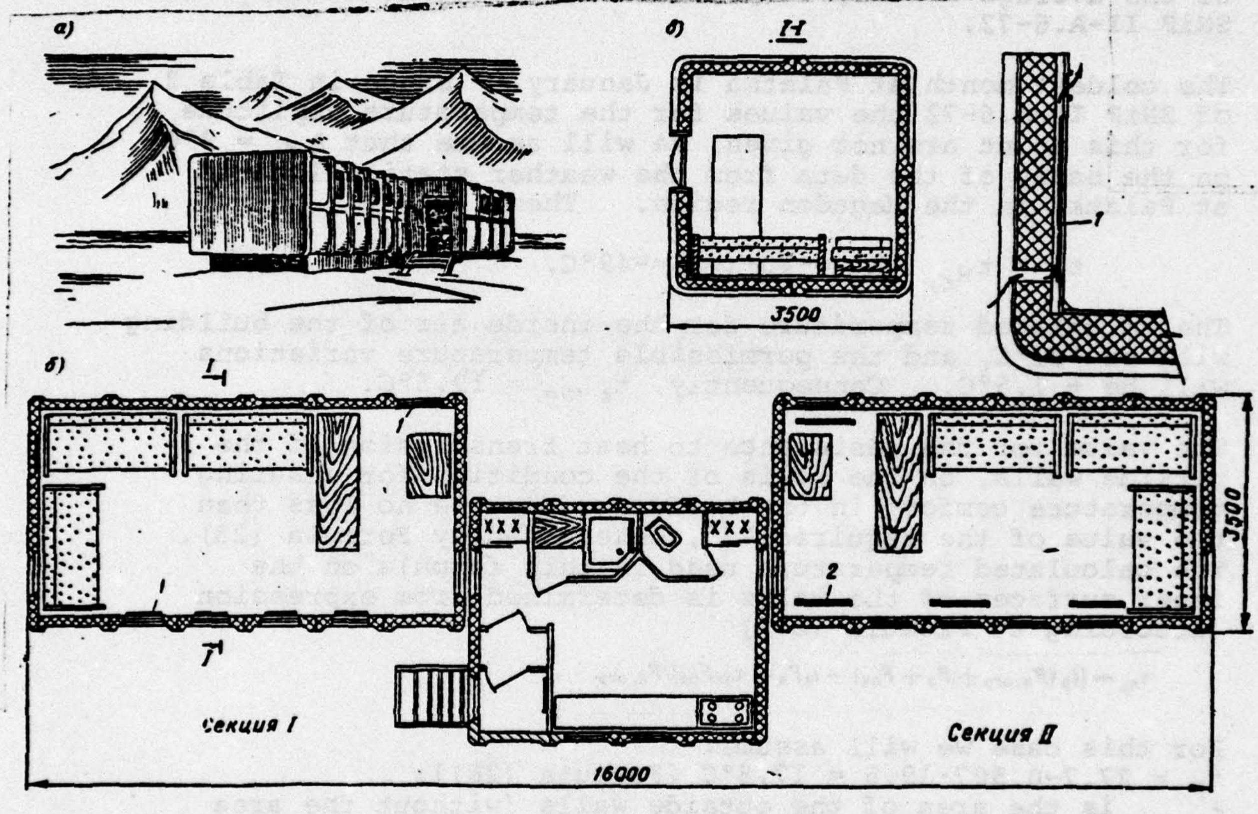
for heater $\lambda_{из} = 0.035$; $s_{из} = 0.35$;

for the fiberboard layer $\lambda_{д.б.} = 0.24$; $s_{д.б.} = 6.12$.

If we assume that the thickness of the layer of heating material is equal to 150 mm, if we substitute into Formula (29) the values obtained, we will have

D = 9.2·0.004:0.65+0.35·0.15:0.035+6.12·0.014:0.24 = 1.91< 2.

Figure 4. Plastic House Made of Individual Parts.
a- outside appearance; b - plan; c - cross-section; 1 - low temperature electric panels; 2 - electric radiators.



The structure of the walls with this degree of solidity must be considered to be particularly light. The distinguishing feature is that the damping of the temperature variations in them is independent of the thermal inertia, and for a given wall (with a given resistance to heat transmission R_o) is a value which is constant and equal to $\nu_t = R_o/R_b$. Since the daily temperature waves through each wall are transmitted with minimum damping, the calculated temperature for the outside air is the temperature which is equal to the sum of $T_{н.ср}$+ $A_н$ where $t_{н.ср}$ is the average temperature of the coldest days taken from Table 1 of SNiP II-A.6-72. In the case of the Palatka settlement $T_{н.ср}$ = -40°C; $A_н$ is the average daily temperature amplitude of the coldest month, taken from Table 2 of SNiP II-A.6-72. The coldest month is chosen on the basis of the minimum value of the average monthly temperature according to Table 1 of SNiP II-A.6-72.

The coldest month at Palatka is January. Since in Table 2 of SNiP II-A.6-72 the values for the temperature amplitude for this point are not given, we will assume that $A_н$ = 9°C on the basis of the data from the weather station located at Palatka in the Magadon region. Then

$$t_н = t_{н_{ср}} + A_н = -40+(-9) = -49°C.$$

The calculated temperature for the inside air of the building will be +21°C, and the permissible temperature variations will be ± 1.5°C. Consequently, $t_{в\,min}$ = 19.5°C.

The value for the resistance to heat transmission of the outside walls, on the basis of the condition for ensuring temperature comfort in the building, must be no less than the value of the required $R_0^{тр}$, determined by Formula (28). The calculated temperature used in this formula on the inner surfaces of the walls is determined from expression [according to Fromula (27)]

$$\tau_{в_р} = [t_р(F_{н.огр} + F_в + F_{ок}) - t_в F_в - \tau_{ок} F_{ок}]/F_{н.огр}.$$

For this case we will assume:
t_p = 27.7-0.507·19.5 = 17.8°C [Formula (26)];

$F_{н.огр}$ is the area of the outside walls (without the area of the windows) -71 m^2;

$F_в$ is the area of the inside walls (the wall adjacent to the building block is assumed to be the inside wall) - 7.5 m^2;

$F_{ок}$ is the area of the windows - 2.5 m^2;

$t_в$ it is assumed that the inside walls have a temperature equal to the air temperature of the building in this case +21°C;

$\tau_{\text{ок}}$ is the temperature on the inner surface of a window, °C.

A window with triple glazing has a total thermal resistance equal to 0.6 m^2 per hour·°C/kcal so that the temperature of the inner surface is

$$\tau_{\text{ок}} = t_{\text{в}} - R_{\text{в}}(t_{\text{в}}-t_{\text{н}}):R_{\text{ок}} = 21 - 0.133(21+48):0.6=5.7°\text{C};$$

$$\tau_{\text{вр}} = [17.8(71+7.5+2.5)-21\cdot 7.5=5.7\cdot 2.5]:71 =17.9°\text{C}$$

The required resistance to heat transmission of the outside walls is

$$R_0^{\text{тр}} =1(21+49):[7.5(21 - 17.9)] = 3\ \text{m}^2\cdot\text{hours}\cdot°\text{C/kcal},$$

so that the required thickness for the insulating layer is

$$\delta_{\text{из}} = [R_0^{\text{тр}} -(R_{\text{в}}+R_{\text{р.в.}}+R_{\text{с.т.}}+R_{\text{н}})]\lambda_{\text{из}} b = [3 -(0.133+0.058+0.006+0.05)]\cdot 0.035\cdot 1.1 = 0.11\ \text{m} = 11\ \text{cm},$$

where b is the quality coefficient of the heat insulation.

Let us assume that the thickness of the heat insulation made of polystyrene foam is 11 cm.

Illumination of Residences

One of the principal hygienic requirements for residences is providing them with good natural and artificial illumination. Sunlight is a powerful health factor in the environment, under whose influence metabolism and well being are improved, the tone of the nervous system is increased, and working capacity is improved. Proper illumination by the sun's rays has a positive influence upon the microclimate of buildings, improving their temperature and humidity conditions. A lack of light in a building causes certain diseases to develop in people.

We shall assume that the natural illumination of residences is a satisfactory condition if the area of the floor is greater than the glazed area of the windows by no more than a factor of eight. However, it is necessary to avoid a purely geometric standardization of window size as a function of room size, since the amount of light in a room from natural light sources is largely influenced by the light-climatic features of the construction site, the length of the day, the surrounding landscape, and the external natural conditions which influence man in a psychological fashion.

Thus, in northern regions during the Polar Night with its severe frosts and blizzards people try to cover the windows with shutters or hang them on the sides of the building. However in summer the sun which never sets disturbs normal vital activity in man, depriving him of a full measure of sleep and rest, leading to fatigue of the organism and nervous overstress. In southern regions the intensive solar radiation through the windows causes overheating of buildings. Therefore, when designing the windows, it is necessary to keep in mind the required structural solutions which could be used to provide protection against harmful outside influences on the building.

Insufficient or improperly provided electrical illumination, with bright and dark areas in the room, disturbs normal eye function and causes visual fatigue.

The light from fluorescent lights ("daylight"), which has come into wide use recently, approaches the characteristics of sunlight, which is its principal hygienic advantage. These lamps produce a soft diffuse light without any shadows, and do not heat the air; the brightness of their uniform illumination is many times less than that from incondescent lights.

The general illumination in residences is deemed sufficient if it is 10-15 watts per m^2 of area. This value varies as a function of many conditions: the purpose of the room, the type of electrical equipment, the material and color of the decorations in the room, and so forth.

Results of Natural Heat Engineering Studies of Buildings in Northern Regions

Thusfar, heat engineering investigations of residences have been carried out on the basis of two principal trends: (1) heat-engineering studies of wall structures, temperature-humidity conditions in buildings and the operation of heating and ventilating equipment, conducted by heat engineers and physicists in order to determine the positive and negative characteristics of structural solutions adopted for buildings; (2) sanitary and hygienic studies of microclimates of residences, conducted by physicians and hygienists in order to determine the influence of the principal microclimatic parameters on the thermal sensations in man. Unfortunately these mutual investigations often were carried out in a disorganized manner, so that their results need not necessarily have actually been used in construction.

The organization known as LenZNIIEP, together with the Departments of Physics and Architecture of LISI and the Department of Communal Hygiene of the Leningrad Sanitary-

Hygienic Medical Institute (M.N. Grigor'yev) have done some work in recent years on the combined physical and hygienic investigation of the microclimate of buildings and on the development of new optimum structural solutions for buildings and engineering equipment, as well as on working out methods of investigation and thermotechnical calculation.

The tests were conducted in buildings of an old design and also in newly constructed multi-story large residences, not to mention portable buildings of a light construction. The studies in the first climatic zone and in the Northern Regions revealed a number of important factors that influenced the service life and heat protective properties of walls as the influence of the microclimate of a building upon the temperature sensations of the people living inside.

The natural studies carried out in the field with residences consisting of multiple stories showed that the temperature and humidity conditions depend upon the heat-protective properties of the structure and in particular on the quality with which the construction work was carried out. A high level of moisture in the materials on the outside walls causes a relatively low temperature on the inside surfaces and leads to considerable pressure drops both vertically and horizontally with the building.

The most unfavorable temperature conditions are those in corner rooms and apartments on the second floor when there are breezeways and passageways under the building. In the corner rooms, the disturbance of the comfort conditions may be due to the increased surface of the outside walls, which increase the radiation heat loss by man. Even at temperatures of 21 -22°C up to 70% of the residents usually characterized the temperature conditions as "chilly" and at temperatures less than 20°C (on days with frost) almost everyone who was asked responded that they were "cold". In the apartments on the second floor the temperature difference between the air in the room and the surface of the floor was much higher than normal (2°C).

The principal shortcoming of all of the buildings that were studied in northern areas was the low relative humidity of the air in the buildings. The artificial humidification of the air by means of pans of water placed on the radiators did not yield the desired effects. With strong winds in winter there is a sharp drop in temperature in buildings that are on the windy side. Infiltration of cold air through the gaps between the windows and also the joints creates uncomfortable conditions in the apartments with low temperatures and high wind speeds (more than 0.3 - 0.4 m/second). Poor sealing of the windows causes condensation and frost on those areas that are adjacent to the windows.

Recently, in conjunction with construction work on large-scale portable and collapsible buildings for use in northern regions, employing the new efficient materials, the question of the microclimate for buildings has become particularly timely. Tests of the first samples of these portable homes reveal the shortcomings of the present method of heat engineering calculation of the outside walls and the temperature-humidity conditions for residences. In the first houses (the type VO-6 portable residence), built by the Bugul'min Combine of Production Enterprises, the microclimate in the buildings failed to satisfy the temperature comfort conditions and the construction of the walls was in an unsanitary state. Even at outside air temperatures of -25 to -30° the walls became damp and the corners of the room showed formation of frost. The floors, which showed a resistance to heat loss of 3.5 - 4.0 $m^2 \cdot$hourX°C/kcal had a surface temperature of +10 - +12°C, which is much less than the admissible value. People who lived in these houses covered the floors with sawdust but this did not result in the desired temperature increase on the surface of the floor. The temperature difference with height in the room was more than 8-10°C. The need for running the heating system for the house all day long made their use more difficult. Due to the low temperature stability of both the outside walls and the buildings as a whole, the average daily temperature variations for the air in the buildings was more than 5-6°C. Even with an inside air temperature of +22°C the people felt chilled due to the considerable heat losses through radiation to the outside walls (the outside walls are the three walls, floor and ceiling). Wooden screens were built around the doors of all the houses to protect them against wind and snow.

The organization known as LenZNIIEP has designed and built an experimental model of a house with a plastic structure, intended for use in northern regions. The heat engineering calculations for the outside walls of the house took into account the characteristic features of the design (their low thickness and mass, and consequently low thermal stability) the architectural planning design for the house (the provision of a large area for outside walls), the influence on man of radiation temperatures from the inside surfaces, the harsh climatic conditions in the North, and the experience gained in using the first mobile homes. The resistance to heat transmission of the outside walls was determined on the basis of the conditions for ensuring temperature comfort for man in houses.

The plastic house was provided with bedrooms, a dining room, kitchen, a double vestibule, shower, toilet and closets for drying clothing and footwear (see Figure 4). The principal structural elements of the building were as follows: L-shaped mass-produced panels with and without windows and flat end walls, with an opening for a door and without. The outside panels were made of a protective layer - plexiglas,

3-4 mm thick, a layer of heat insulation made of polystyrene foam 150 mm thick, and an inside layer made of wood fiber paneling. The windows, 70 x 70 cm, were made of transparent plastic in three layers. The house was fitted with convective-exhaust ventilation. The electric heating panels were mounted beneath the inside facing of the outside structure in the air space that communicated between the outside and inside air.

The complicated thermophysical and sanitary-hygienic tests in an experimental house were conducted between January 10 and February 10, 1970 in the settlement of Palatka in Magadan Region, at outside temperatures of -40 to -45°C, close to the calculated value of -50°C.

The sensors for measuring the temperatures were chromel-copel thermocouples, while the heat fluxes passing through the outside walls were determined by using thermocouples of a design developed by the Leningrad Technological Institute of the refrigerating industry. Recording of the temperature and heat flux was accomplished automatically using type EPP-09 electronic potentiometers.

The results of the thermophysical studies showed that the designs of the walls completely satisfied the heat insulating requirements which would ensure temperature conditions required for residences.

In addition to the study of the thermo-physical parameters of the outside structure and the microclimate in the plastic house, several thermoregulatory reactions of human beings were determined, and they were questioned about how they felt about the temperature.

One of the criteria for evaluating the processes of thermoregulation is the skin temperature in man. The skin temperature on different parts of the human body within the limits of the comfortable environmental temperature range is as follows:

On the skin of the forehead, 33.2°C; on the chest - 33.5°C; on the wrists 30.4°C, on the foot - 26.5 - 27.0°C. Discomfort was recorded in those cases when the skin temperature on the forehead was below 32°, 31° for the trunk, 30° for the fingers, and 25°C for the legs.

When performing experiments, the skin temperature was measured using an electrical thermometer in four men aged from 28 to 40. The subjects were dressed identically: knitted underwear, cotton shirt, trousers, and socks and house slippers on their feet. The skin temperature was

measured at six points after 30 minutes adaptation to the ambient conditions: forehead, chest, wrist, thigh, shin, foot. At the same time, the subjects were asked about how they felt, rating their sensations on a 5 point scale: cold, cool, comfortable, warm, hot. The studies were conducted at an indoor temperature between 16 and 22°C.

The results of the temperature measurements in these subjects are shown in Table 3. When the air temperature rises from 16 to 22°C, the skin temperature on all parts of the body with the exception of the wrists increased uniformly, but it was greater on the upper part of the trunk than in the distal portions of the extremities. On the basis of the data shown in the table, the most comfortable temperature in the room is +22°C.

Table 3: Skin Temperature of Subjects at various Temperatures of the Air in the Room

Body Area	Air Temperature °C			
	16	18	20	22
Forehead	31.6	32.2	32.8	33.3
Chest	33.0	33.5	33.7	33.8
Wrist	25.4	29.4	28.9	29.9
Thigh	30.6	31.3	32.0	32.5
Shin	29.1	29.7	30.2	30.6
Foot	21.3	22.2	23.9	24.8

For overcooling situations, it is sufficient to determine the temperature of the distal portions of the extremities, especially the feet. The latter react most clearly to temperature changes in the air and the floor. Regardless of the fact that the thermal resistance of the floor was increased relative to the calculated value, the temperature at its surface was found to be rather low and reached 16°C, while the temperature drop between the floor and the air 25 cm above it reached 5 to 6°C.

The temperature gradient of the skin of the distal and proximal (closer) parts of the extremities turned out to be considerable in view of the low temperature of the skin of the foot. Thus, at an air temperature of t_{air} = 18°C, the temperature difference between the chest and the foot was 11.3°C, while with t_{air} = 16°C it was 11.7°C. The information from the questions asked about comfort of the subjects indicated that at all air temperatures in the room their feet were cold, while at only 16 - 17°C the individuals characterized their feelings as "cold" at

18 -20°C as "good" and at 22°C as "hot".

In the test building, the resistance to the heat transmission of the outside walls ensured a temperature difference between the air and the surface of the wall of 2 - 3°C. The determination of one of the heat exchange parameters of the organism from the environment - the level of infra-red radiation from the exposed and covered parts of the human body into the room - was conducted by means of a differential radiometer designed by the Moscow Scientific Research Institute of Hygiene named after F.F. Erisman.

The intensity of the infra-red radiation from the chest varied from 0.96 to 1.04, from the forehead between 0.85 and 0.92, from the wrist between 0.56 to 0.65, from the surface of the clothing, 0.67 to 0.71 calories per cm^2·hour. The lowest parameters were obtained on the foot, where the radiation amounted to 0.34 - 0.54 calory/cm^2·hour. The radiation from the surface of the clothing to the walls, determined on the basis of satisfactory microclimatic conditions in a house in Vorkuta (F.F. Lampert and M.G. Makeyeva) was 2.4 calories/cm^2·hour. The data obtained indicate that the radiation heat losses in man under conditions of exposure in the experimental house were low.

When the house is sharply cooled (with the heat shut off) no major changes in the skin temperature and infra-red radiation were observed. Thus for example subject N, when the air temperature fell from 21 to 17°C within 2 hours, showed a drop in his skin temperature by 0.9°C, on the forehead, 0.5° on the chest, 1.4° on the wrist, 1.1° on the thigh 0.5° on the shin and 0.6°C on the foot. During this same period of time, the magnitude of the radiation at the wall increased for the forehead from 0.8 to 1, for the chest from 1 to 1.2, the wrist from 0.6 to 0.7 calorie/cm^2·hour, indicating a slow drop in temperature on the inside surfaces of the walls (due to the considerable resistance to temperature changes of the outside walls, $R \approx 4$ m^2·hours·°C/kcal).

The natural thermophysical and sanitary-hygienic investigations of buildings confirm the considerable influence of the temperature of the limiting structures on the temperature comfort of man and the need in heat engineering calculations for outside walls to take into account not only the temperature of the inside air but also the average radiation temperature of the room, particularly in apartments with a large area of outside wall (corner rooms, apartments on upper floors, portable buildings and those that can be taken apart and assembled again). In apartments on the second floor of houses that have breezeways beneath them (passageways), artificial heating of the floor is necessary to maintain the required temperatures on their surfaces.

The outside walls not only must protect the room against extreme decreases or increases in temperature of the outside air, but must also provide the required temperature conditions in the room under the influence of varying thermal influences.

Testing of buildings for thermostability with periodic stove heating was a necessary condition for the construction planning. The changeover to central heating, using traditional solid walls, improved the conditions for maintaining the required temperature of the inside air and did away with the need for such tests.

In recent years, when solid buildings made of bricks and concrete have been succeeded by those in which new light types of construction are employed, when residences and business buildings are built with a great many stories, mobile and take-apart buildings for special purposes (settlements for geologists, petrolium prospectors, hunters and reindeer breeders in Northern regions), are being built even more, the problems of thermostability of buildings has become timely once more.

Light concrete and cellular plastics, fiberglas and transparent films, thin walled reinforced concrete elements, etc. are presently extending the range of traditional structural materials (bricks, solid concrete, slag and the like) in wall structures. The use of efficient new materials in modern construction is making it possible to reduce considerably the thickness and the weight of the wall structures, but has produced a sharp drop in the temperature inertia.

DISTRIBUTION OF TEMPERATURE VARIATIONS IN OUTSIDE WALLS

The thermostability of outside walls is estimated by the damping of the amplitude of the temperature variations with the thickness of the wall, i.e., their ability to produce greater or smaller variations in temperature on the inside surface with variations in the magnitude of the transient heat flux through the wall. The damping of the temperature variations in the wall is a function of the degree of its massiveness D = Rs, which is determined by formula (29).

The damping of a temperature wave in a multi-layer wall is found by expression [10]

$$\bar{v}_t = \bar{v}_1 \bar{v}_2 \ldots \bar{v}_n \bar{v}_n = e^{\Sigma Rs/\sqrt{2}} [(s_1 \sqrt{\bar{i}} + \alpha_n)/(s_1 \sqrt{\bar{i}} + \bar{Y}_1)] [(s_2 \sqrt{\bar{i}} + \bar{Y}_1)/(s_2 \sqrt{\bar{i}} + \bar{Y}_2)] \ldots \ldots \bar{Y}_{k-1}/\bar{Y}_k \ldots [(s_n \sqrt{\bar{i}} + \bar{Y}_{n-1})/(s_n \sqrt{\bar{i}} + \bar{Y}_n)] (\bar{Y}_n + \alpha_n)/\alpha_n, \quad (30) \tag{30}$$

where

$\bar{\nu}_1, \bar{\nu}_2$ - damping of the temperature wave in the individual layers of the wall;

$\bar{\nu}_H$ - damping of the temperature wave with a transition from the outside air to the inside surface of the wall;

$\bar{Y}_1, \bar{Y}_2$ - the coefficient of heat assimilation of the surface of the individual layers of the wall, kcal/m^2·hour·°C;

s - coefficient of thermostability of the material of the wall, kcal/m^2·hour·°C;

α_B - coefficient of heat uptake, kcal/m^2·hour·°C;

α_H - coefficient of heat loss, kcal/m·hour·°C.

Damping $\bar{\nu}_t$ is a complex number, whose modulus expresses the damping of the amplitude and the argument represents the phase lag of the temperature ossilations. In approximate calculations, the modulus of damping of a temperature wave in a multi-layered wall can be determined by using the formula

$$\nu_t = e^{\Sigma Rs/\sqrt{2}}\,[(s_1+\alpha_в)/(s_1+Y_1)][(s_2+Y_1)/(s_2+Y_2)]\ldots Y_{k-1}/Y_k\ldots \ldots[(s_n+Y_{n-1})/(s_n+Y_n)](Y_n+\alpha_н)/\alpha_н \quad (31) \tag{31}$$

[in contrast to equation (30), in (31) Y is represented by a real number].

For a single-layer wall (31) assumes the form

$$\nu_t = e^{Rs/\sqrt{2}}\,[(s_n+Y_{n-1})/(s_n+Y_n)](Y_n+\alpha_н)/\alpha_н = e^{Rs/\sqrt{2}}\,[(s_n+\alpha_в)/(s_n+Y_n)](Y_n+\alpha_н)/\alpha_н, \tag{32}$$

while when D = Rs $\geq$ 1(i.e., $Y_n = s_n$)

$$\nu_t = 0{,}5^{Rs/\sqrt{2}}\,[(s_n+Y_{n-1})/s_n](s_n+\alpha_н)/\alpha_н = 0{,}5^{Rs/\sqrt{2}}\,[(s_n+Y_{n-1})/s_n](s_n+\alpha_н)/\alpha_н = 0{,}5^{Rs/\sqrt{2}}\,[(s_n+\alpha_в)(s_n+\alpha_н)]/s_n\alpha_н; \tag{33}$$

if D = Rs < 1,

$$\nu_t = e^{Rs/\sqrt{2}}\,[(1+R_вY_{n-1})/(1+R_вs_n)](Y_n+\alpha_н)/\alpha_н = e^{Rs/\sqrt{2}}\,(1+R_в\alpha_в)(\alpha_в+\alpha_н)/(1+R_вs_n)\,\alpha_н. \tag{34}$$

The coefficients of heat accommodation of outside surfaces of individual layers of wall Y are determined as follows:

if $D \geq 1$ in the layer, we will have $Y_n = s_n$, i.e., it will be equal to the coefficient of heat accommodation of the material of this layer; if $D < 1$ in the layer, its value Y will be calculated by the formula

$$Y_n = (R_n s_n^2 + Y_{n-1})/(1 + R_n Y_{n-1}). \quad (35)$$

The damping of a temperature wave in a wall will be minimal with the specific thermal capacity of the material of the wall c is very small or the period of the temperature variation T is very large, i.e., when the degree of massiveness of the wall D tends toward zero. Under these conditions the damping of the temperature variations in the wall with a given value R_o can be determined as follows

$$\nu_{t_{min}} = R_o/R_в, \quad (36)$$

where $R_o = R_H + R_n + R_в$;

R_H is the resistance to heat loss on the outside surface, $m^2 \cdot hour \cdot °C/kcal$;

R_n is the thermal resistance of the structure of the wall, $m^2 \cdot hour \cdot °C/kcal$;

R is the resistance to heat absorption at the internal surface, $m^2 \cdot hour \cdot °C/kcal$.

In this case, any temperature variations adjacent to the wall in question of the medium are transmitted without delay to the opposite surface of the wall with a reduction of R_o/R_b times, i.e., as in a stationary heat transmission.

It is obvious that when D = Rs tends toward zero ν_t will tend toward $\nu_{t\,min}$, and their ratio $\nu_t/\nu_{t\,min}$ will tend toward unity.

The graph (Figure 5) shows the relationship

$$\nu_t/\nu_{t_{min}} = f(D = Rs) \quad (37)$$

for various single-layer and multi-layer walls. Calculation of the damping of the temperature variations in the walls was performed using approximate formulas (31), (33), and (34). To check relationship (37), we performed calculations on a "Nairi" computer according to Formula (30). The data obtained with the computer are practically the same as the values that were calculated using the approximate formulas.

The results of these investigations show that the influence of the thermal inertia on the damping of the temperature

oscillations in walls decreases with decreasing massiveness of the latter, while when D = Rs < 2 it is practically zero, i.e., with a slight allowance we can assume that the damping of the temperature oscillations ν_t is independent of the thermal inertia of the design and at given R_O and R_β it is a constant value and one which is equal to $\nu_t = \nu_{t\,min} = R_O/R_\beta$. The amplitude of the temperature oscillations on the internal surface of the wall can then be determined as follows:

$$A_{в} = A_{н} R_{в}/R_{о}, \tag{38}$$

Where A_H is the amplitude of the temperature variations of the outside air, °C.

Let us represent the value $\nu_t/\nu_{t\,min}$ by μ and call it the factor of thermal inertia of the wall. Then in the case of wall structures in which D > 2, the amplitude of the temperature variations on their internal surfaces will be determined by the formula

$$A_{в} = A_{н} A_{в}/\mu R_{о}. \tag{39}$$

Relationship (37) may be represented by the equations:

with D > 2

$\mu = 1;$

with 2 < D ≤ 4

$$\mu = 0.35(D - 2)^2 + 1; \tag{40}$$

with 4 < D ≤ 7

$\mu = 1.55(D - 4)^2 + 2.4$

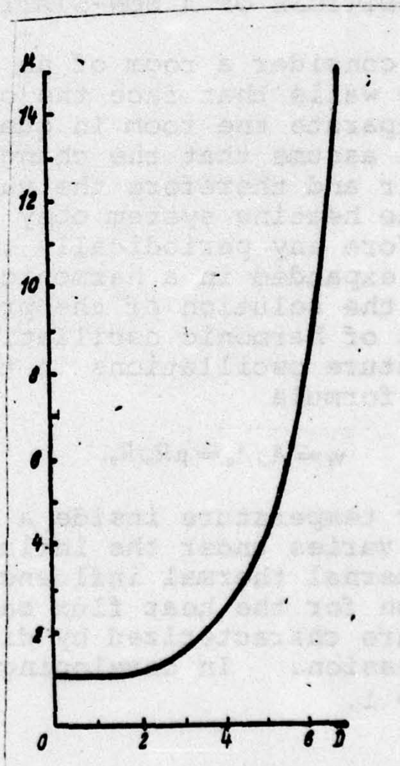


Figure 5. Relative damping of temperature waves in wall structures as a function of their degree of massiveness.

It appears to be advantageous to construct walls which have $D \leq 2$ in the classification of the wall structures; by degree of massiveness they can be classified into an independent class of particularly light construction, while the class of light construction can be further delimited by the limits $2<D\leq 4$. In determining the resistance to heat transmission of the outside walls on the condition of ensuring temperature comfort in a room for a calculated Winter temperature of the outside air t_H for particularly light wall structures, we must assume a temperature

$$t_{н} = t_{н_{cp}} + A_{н}, \tag{41}$$

where t_{HCP} is the average temperature of the coldest days, °C;

A_H is the average daily temperature amplitude of the coldest month which is expressed on the basis of the minimum value of the average monthly temperature, °C.

When testing the resistance to heat transmission of walls on the basis of the condition of temperature resistance of the room for structures of all classes of massiveness, the calculated winter temperature of the outside air must be assumed to be equal to the average temperature of the coldest days.

CALCULATION OF THE INSIDE TEMPERATURE OF ROOMS UNDER *THE CONDITIONS OF A NON-STATIONARY TEMPERATURE REGIME.*

Let us consider a room of an arbitrary shape, which has outside walls that face the outside air and inside walls that separate the room in question from the adjacent ones. We will assume that the changes in temperature of the outside air and therefore the variations in the heat flux from the heating system obey the law of harmonic oscillations (therefore any periodically repeating changes in temperature can be expanded in a harmonic Fourier series and we can reduce the solution of the problem to a summation of the effects of harmonic oscillation). The damping of the temperature oscillations in the wall structures is determined by the formula

$$\nu_t = A_н/A_в = \mu R_0/R_в. \tag{42}$$

The air temperature inside a room with a non-stationary regime varies under the influence of alternating external and internal thermal influences. Let us develop the equation for the heat flux balance in a room whose outside walls are characterized by different resistances to heat transmission. In developing this equation we will assume that $\mu = 1$.

The change in the transitional heat flux through the outside walls due to temperature variations in the outside air is determined as follows:

$$\Delta Q^{I} = (A_{н}\cos\alpha_1/R_{o1})F_{н1} + (A_{н}\cos\alpha_2/R_{o2})\cdot F_{н2} + \ldots$$
$$\ldots + (A_{н}\cos\alpha_n/R_{on})F_{нn} = A_{н}\sum_{i=1}^{n} F_{нi}\cos\alpha_i/R_{oi}. \quad (43)$$

The value $\cos\alpha_i$, which is used in Fromula (43) is determined on the basis of the following relationship:

$$\cos\alpha_i = (\tau_{A_н} - \tau_x)\omega + 57{,}3R_i s_i/\sqrt{2},$$

where $\tau_{Aн}$ is the moment in time which corresponds to the maximum temperature of the outside air, hours;

τ_x is the moment in time which corresponds to the determination of the temperature, hours;

$\omega = 2\pi/T$;

T is the period of the temperature variations, hours;

$57{,}3R_i s_i/\sqrt{2}$ is the value which takes into account the lag in the temperature wave as it passes through the wall;

s_i is the coefficient of thermal adaptation by the wall material, kcal/m^2·hour·°C.

The change in the heat flux which enters the room from the heating system,

$$\Delta Q^{II} = qm\cos\beta, \quad (44)$$

where

$$q = (t_в - t_н)\sum_{i=1}^{n} F_{нi}/R_{oi}; \quad (44a)$$

m is the coefficient of inequality of heat released by the heating devices;

$\cos\beta = (\tau_{max} - \tau_x)\omega$;

τ_{max} is the moment in time which corresponds to the maximum output of heat from the heating devices, hours;

The change in heat flux, absorbed by the inside surfaces of the wall structures in the room, is determined by the expression

$$\Delta Q^{III} = \Delta t_в\left(\sum_{i=1}^{n} B_{нi}F_{нi} + \sum_{i=1}^{m} B_{вi}F_{вi}\right). \quad (45)$$

where Δt_B is the variations in the temperature of the air in the room at the moment in time in question from the average value, °C;

F_{Hi}, F_{Bj} are the areas of the inside surfaces of the outside and inside walls, respectively, m^2;

B_{Hi}, B_{Bj} are the coefficients of heat absorption of the inside surfaces of the outside and inside walls, respectively, $kcal/m^2 \cdot hour \cdot °C$.

The coefficient of heat absorption of the surface of the wall is numerically equal to the amplitude of the oscillations in the heat flux, passing through the surface of the wall, with the amplitude of the oscillations in the temperature of the air in the room being 1°C, and determined by expression

$$B = 1 : (1/\alpha_B + 1/Y_B), \tag{46}$$

where α_B is the coefficient of heat perception on the inside surface of the wall, $kcal/m^2 \cdot hour \cdot °C$;

Y is the coefficient of heat accommodation of the inside surface of the wall, $kcal/m^2 \cdot hour \cdot °C$.

The oscillations in heat flux, which produce the heating of the air in the room,

$$\Delta Q^{IV} = \Delta t_B C_0 V_0 \omega, \tag{47}$$

where C_0 is the volume heat capacity of the air, $kval/m^3 \cdot °C$;

V_0 is the volume of the air in the room, m^3.

In the room, there must be a heat balance between the heat which is passing through the outside walls, the heat which is coming from the heating system, and the heat which is picked up by the internal surfaces of the outside walls and the internal air of the room, i.e.

$$\Delta Q^{I} + \Delta Q^{II} = \Delta Q^{III} + \Delta Q^{IV} \tag{48}$$

or

$$A_H \sum_{i=1}^{n} F_{Hi} \cos\alpha_i / R_{0i} + (t_B - t_H)\, m \sum_{i=1}^{n} \cos\beta_i \cdot F_{Hi}/R_{0i} = \\ = \Delta t_B \left(\sum_{i=1}^{n} B_{Hi} F_{Hi} + \sum_{j=1}^{m} B_{Bj} F_{Bj} \right) + \Delta t_B C_0 V_0 \omega. \tag{49}$$

The second term on the right-hand side of equation (48), due to its small size, may be disregarded, since the thermal capacity of the air is negligibly small. Then, from the last equation the desired value for the variations in the

temperature of the inside air in the room can be determined as follows:

$$\Delta t_{в} = \left[A_{н} \sum_{i=1}^{n} F_{нi} \cos \alpha_i + m (t_{в} - t_{н}) \times \right. \tag{50}$$

$$\left. \times \cos \beta \sum_{i=1}^{n} F_{нi} \right] : \left[R_{o_{cp}} \left(\sum_{i=1}^{n} B_{нi} F_{нi} + \sum_{j=1}^{m} B_{вj} F_{вj} \right) \right],$$

where

$$R_{o_{cp}} = \sum_{i=1}^{n} F_{нi} : \sum_{i=1}^{n} F_{нi} / R_{oi}.$$

The amplitude of the temperature variations of the inside air in the room, on the condition of the phase-coincidence of the oscillations in the transitional heat flux through the outside walls and the variations in the heat flux from the heating devices, from equation (49), will be

$$A_{в} = [A_{н} + (t_{в} - t_{н}) m] F_{н} / R_{o_{cp}} \cdot (B_{н} F_{н} + B_{в} F_{в}), \tag{51}$$

and, taking into account the damping of the temperature waves as a function of the thermal inertia of the walls [see (39)] the last equation will have the form

$$A_{в} = [A_{н} + \mu m (t_{в} - t_{н})] F_{н} / \mu R_{o_{cp}} \cdot (B_{н} F_{н} + B_{в} F_{в}). \tag{52}$$

Equation (51) describes the thermal regime of the room during winter in the presence of a varying heat flux through the outside walls (due to the variations in the temperature of the outside air) and the varying amounts of heat coming in from the heating system.

During the summer, when the heating system is not operating, the amplitude of the temperature variations of the air in the room with a non-stationary thermal regime is determined as follows:

$$A_{в}^{л} = A_{н.ус} F_{н} / \mu R_{o_{cp}} \cdot (B_{н} F_{н} + B_{в} F_{в}). \tag{53}$$

In this case, $A_{н,ус}$ is the calculated amplitude of the oscillations in the conditional outside temperature taking into account the solar radiation on the surface of the wall.

ESTIMATION OF THERMAL STABILITY OF THE ROOM

The thermal stability of a room is evaluated on the basis of its ability to affect the decrease in the amplitude of

the oscillations of the inside air temperature with oscillations in the heat flux given off by a heating device [8]. Absolutely no consideration is given to the influences on the heat regime of the room by temperature oscillations of the outside air, as well as the effects of the solar radiation on the outside walls.

Consequently, the thermal stability of the room will be characterized more correctly on the basis of its ability to produce greater or smaller variations in the temperature of the inside air from its average value under the influence of varying thermal effects [5]. The varying thermal effects must include both the thermal effects of the heating system and the external temperature variations.

The amplitude of the temperature variations in the air in the room relative to the external thermal influences (summer time) on the condition

$$R_1 = R_2 = \ldots = R_{o_{cp}} = R$$

from equation (53) is determined as follows

$$A_в^л = A_{н.\,ус} F_н / \mu R \cdot (B_н F_н + B_в F_в). \tag{54}$$

The amplitude of the temperature variations of the air in the room relative to the variations in the temperature of the outside air and the variations of the heat flux from the heating devices (inter) under the condition of equality of the thermal resistances of the outside walls from equation (52) can be determined as follows

$$A_в^з = [A_н + \mu m (t_в - t_н) F_н] / \mu R (B_н F_н + B_в F_в). \tag{55}$$

The variations in the heat flux from the heating devices will be viewed as external influences relative to the variations in the air temperature in the room. Then the numerator of the fraction on the right-hand side of equation (55) may be represented as the amplitude of the total external temperature influences on the room:

$$A_н + \mu m (t_в - t_н) = A_{н.\,сум}, \tag{56}$$

and equation (55) will read as follows:

$$A_в^з = A_{н.\,сум} F_н / \mu R (B_н F_н + B_в F_в). \tag{57}$$

Representing $A_{H,lc}$ and $A_{H,cym}$ by A_H, the damping of the amplitude of the temperature variations of the inside air relative to the amplitude of the outside temperature effects, on the basis of formulas (54) and (57), may be represented as follows:

$$A_H/A_B = \mu R(B_H F_H + B_B F_B)/F_H,$$

or

$$A_H/A_B = (B_H F_H + B_B F_B) : F_H/\mu R. \tag{58}$$

The sum $(B_H F_H + B_B F_B)$ in the numerator of the fraction on the right-hand side of equation (58) represents the total heat absorption by the room, which is numerically equal to the amplitude of the heat flux which is absorbed by all of its inside surfaces with an amplitude for air temperature variations of 1°C.

The value $F_H/\mu R$ represents the transitional heat flux through the outside walls with a temperature difference of 1°C. The ratio between these values will characterize the thermal stability of the room. The ratio of the total heat absorption by the room to the transitional heat flux through the outside walls would be represented by :

$$\zeta = \mu R(B_H F_H + B_B F_B)/F_H \tag{59}$$

and would be referred to as the heat stability parameter of the room.

Let us consider the thermal stability of rooms with different thermal inertias. For example we will take four of the most characteristic kinds of rooms (the characteristics of the rooms are shown on Table 4).

Table 4. Computation Table for Determining the Amplitude of the Temperature Variations of the Inside Air in Rooms with different Thermal Stabilities.

No	Characteristics of the Room	F_H, m^2	F_B, m^2	ζ	A_B, °C
1	Room on the mezzanine of a	8.1	76.5	37.5	0.4
2	multi-story building (one window)	8.1	76.5	30.0	0.5
3	Corner room on mezzanine	24.3	60.3	11.5	1.3
4	(two windows)	24.3	60.3	9.4	1.6
5	Corner room on upper	42.3	42.3	7.5	2.0
6	floor (two windows)	42.3	42.3	6.2	2.4
7	Movable house on skis (two windows)	84.6	-	1.4	10.9

All of the rooms in question have the same dimensions (6X3X2.7m) and identical (from the structural standpoint) outside walls with equal resistances to heat transmission, calculated for the climatic conditions of Leningrad according to method SNiP II-A.7-71 (for a qualitative comparison of the thermal stability of the rooms, the choice of climatic region is not of theoretical significance). The distinctive features of the rooms are the ratio of the area of the inner and outer walls as well as the existence of different kinds of thermal-accumulating capacity for the inside walls. The characteristic feature of their thermal inertia is the parameter of thermal stability of the rooms.

Single-layer outside walls of rooms are filled with porous phenol plastic, whose resistance to heat transmission is assumed to be 1.4 $m^2 \cdot hour \cdot °C/kcal$, and the coefficient of heat absorption of the inner surfaces is 0.75 $kcal/m^2 \cdot hour \cdot °C$. The resistance to heat transmission of the windows with double glazing is 0.4 $m^2 \cdot hour \cdot °C/kcal$, and the coefficient of heat absorption of the parquet floor along the layer of light concrete which is laid on the reinforced concrete slab, is 1.9 $kcal/m^2 \cdot hour \cdot °C$. In rooms 1,3 and 5 (see Table 4) the internal wall is made of reinforced concrete 0.14 m thick and has coefficients of thermal absorption of the inner surfaces which are 4.15 $kcal/m^2 \cdot hour \cdot °C$. In rooms 2,4 and 6 the plaster and concrete walls are 0.1 m thick and have a coefficient of heat absorption of 2.53 $kcal/m^2 \cdot hour \cdot °C$. All of the outside walls of the rooms in the movable house are outside walls.

The calculation of the temperature variations in the air in the rooms was carried out under identical external temperature conditions (A = $\pm$ 15°C) using formula (55) and on a hydro-integrator. For each of the rooms in question, a hydromodel was calculated. The results of the solution of the problem on the hydrogenerator are practically the same as the results obtained by the formula given above.

As we can see from the data in the table, the amplitude of the temperature variations of the air in the rooms is different, although these rooms have the same thermal resistances of the outside walls and are subjected to the same external thermal influences. Since the decrease in the parameter of heat stability results in an increase in the temperature oscillations in the rooms, this makes sense. While in the first room these variations were no more than $\pm$ 0.4°C, in the latter, under the same boundary condition ($\pm$10.9°C) they are considerably greater than the permissible variations in residences with central heating ($\pm$-.5°C).

An analysis of these studies of the thermal regime of rooms

has shown that the resistance to the heat transmission of the outside walls, determined using the method SNiP II-A.7-71, does not ensure in any of the rooms that they will be thermally stable and that the calculation of the thermal resistance of the outside walls must be carried out not only on the basis of the conditions for thermal stability of the individual walls, but on the basis of the conditions for thermal stability of the entire room, taking into account its heat-accumulating ability. SNiP mentions the necessity for calculating the thermal stability of the room, but fails to mention the method, giving only the check for the thermal stability of the structure, which cannot be considered adequate.

CHOICE OF THE RESISTANCE TO HEAT TRANSMISSION OF THE OUTSIDE WALLS ON THE BASIS OF THE CONDITIONS FOR THERMAL STABILITY OF THE ROOMS

The variations in the temperature of the inside air in the rooms of residential and public buildings during winter, when the buildings have central heat, must not exceed ±1.5 (and in the case of a furnace ±3°C) during 24 hours. In order to ensure these requirements, the value for the resistance to heat transmission of the outside walls must be at least as large as the required value $R_{з}^{тр}$, determined for winter conditions by the formula

$$R_{з}^{тр}=[A_{н}+\mu m\,(t_{в}-t_{н})]\,F_{н}/\mu\,\Delta t_{в}\,(B_{н}F_{н}+B_{в}F_{в}), \qquad (60)$$

where $A_{н}$ is the average daily amplitude of the temperature of the outside air of the coldest month, determined by SNiP II-A.6-72, °C;

μ is the coefficient of thermal inertia of the wall, determined by formulas (40);

m is the coefficient of inhomogeneity of the transmission of heat by heating devices;

$t_{в}$ is the calculated temperature of the inside air in the room, °C;

$t_{н}$ is the calculated winter temperature of the outside air, °C;

$\Delta t_{в}$ is the permissible variation in the temperature of the inside air in rooms during winter, °C;

$B_{в}$, $B_{н}$ are the coefficients of heat absorption of the inside surfaces of the inside and outside walls, respectively, kcal/m²·hours·°C;

$F_{в}$, $F_{н}$ are the areas of the inside surfaces of the inside and outside walls, respectively, m².

The heat absorption of the windows must be assumed to be zero.

According to SNiP II-A.7-71, the check for the outside walls to determine their thermal stability during summer must only be carried out for regions with an average monthly winter temperature for the outside air of 20°C or more. However, the experimental studies have shown that even in northern regions with average monthly temperatures considerably below 20°C the temperature on the outside surfaces of walls, taking into account solar radiation during summer, is 20-30°C greater than the temperature of the surrounding air, and the variations in the temperature in the majority of regions exceed the winter variations in the temperature of the outside air.

In rooms with massive walls, the influence of solar radiation through the outside walls (with a relatively small period of oscillation) on the thermal regime of the rooms will be insignificant due to the pronounced damping of the temperature waves within the structure. However, in rooms with light, low-inertia walls, even with relatively low temperatures for the outside air, due to the high stress imposed by solar radiation on the outside walls and the low thermal capacity of the latter, there is a sharp increase in temperature on the inside surfaces of the outside walls, and consequently, on the increase in the air temperature in the rooms. Therefore, a check of the thermal protective qualities of the outside walls of residences to determine thermal stability is a necessary condition when designing them under any climatic conditions. The value for the resistance to heat transmission of the outside walls from the condition for ensuring thermal stability of the room during Summer must not be less than the value required $R^{TP}_{Л}$, determined from formula

$$R^{\text{тр}}_{л} = \sum A_{н.\,ус} F_{н} / \mu\, \Delta t_{в} \left(B_{н} F_{н} + B_{в} F_{в}\right), \tag{61}$$

where $A_{н,ус}$ is the calculated amplitude of the variations in the conditional outside temperature for each wall, °C;

Δt_{B} is the permissible variation in the temperature of the air in a room during summer; it is necessary to determine it in accordance with the local conditions, but it must not exceed ±2°C.

The value of $A_{н,ус}$ is taken into account, considering solar radiation on the surface of the wall, and is determined in accordance with the orientation of the walls relative to the direction from which the light comes in accordance with formula [8]

$$A_{н.\,ус} = \left[\rho \left(I_{max} - I_{ср}\right)/\alpha_{н} + A_{t_{н}}\right] \varphi', \tag{62}$$

where ρ is the coefficient of absorption of the solar energy by the outside surface of the wall;

I_{max}, I_{cp} are the maximum and average daily values, respectively, for the total solar radiation (direct and scattered), striking the outside surfaces of the outside walls, used in Table 8 of SNiP II-A.6-72.

α_H is the coefficient of heat loss to the outside surface of the wall, kcal/m^2·hour·°C.

A_{t_H} is the average amplitude of the temperature variations in the outside air during the hottest month of the summer (in regions with a dry climate, it can be assumed to be 9°C, and for regions with a moderate, humid climate- 7°C);

ϕ' is the coefficient of non-simultaneity of the arrival of heat on the outside surface of the wall from solar radiation and from the outside air, determined in accordance with the orientation of the wall according to Table 5.

Table 5. Values for the Coefficient ϕ' as a Function of the Difference in Time between the Maxima of Radiation I_{max}, Temperature t_H and the Ratio of Amplitudes A_{eq}/A_t

A_{eq}/A_t	Various Times I_{max} and t_H 4, hours									
	1	2	3	4	5	6	7	8	9	10
1	0.99	0.96	0.92	0.87	0.79	0.71	0.61	0.50	0.38	0.26
2	0.99	0.97	0.93	0.88	0.82	0.75	0.66	0.57	0.59	0.41
3	0.99	0.97	0.94	0.90	0.85	0.79	0.73	0.66	0.60	0.51
4	0.00	0.98	0.96	0.93	0.89	0.85	0.81	0.76	0.73	0.69

Note: 1. The time of maximum temperature of the outside air is assumed to be 15:00 for all regions.

2. $A_{eq} = \rho(I_{max} - I_{cp})/\alpha_H$.

From the values obtained for R_O^{TP} [formula (28)], R_O^{TP} and R^{TP}, the largest must be used in calculation.

Example. Let us determine the required resistance to heat transmission of the outside walls of a plastic house (Figure 4) on the condition of thermal stability of the room. Cal-

culations are carried out for a living section II (with radiator heat). The proposed region for operation of this house is the Palatka settlement in the Magadan Region. A description of the structure of the outside walls is shown in the example on page 40.

The degree of massiveness of the outside walls with an insulation thickness of 15 cm is 1.91, i.e., $D = Rs < 2$, so that the construction of the outside walls is classified as particularly light. The magnitude of the resistance to heat transmission of the outside walls from the condition of thermal stability of the room in winter must be no less than the value required, R^{req}, determined by Formula (60).

In the calculation, the following are assumed:

A_H = 9°C is the average daily amplitude of the temperature of the outside air of the coldest month (the coldest month in the case of the Palatka settlement is January;

μ is the coefficient of thermal inertia of the wall for particularly light structures, equal to unity;

m is the coefficient of nonuniformity of heat loss from heating devices. In the absence of automatic regulation, the variations in heat output from electric radiators during the 24 hour period would depend only on the variations in the voltage in the power line, which amount to 5-6% of the average value. Consequently m = 0.05;

is the calculated temperature of the air in the room; in the case of Northern regions it is assumed to be equal to _21°C;

t_B is the calculated winter temperature of the outside air; for the case of particularly light walls, we assume in the case of the calculated value that the average temperature of the coldest day will be used which in the case of Palatka is -40°C;

Δt_B is the permissible variation in the temperature of the inside air; we shall assume that it is equal to $\pm$ 1.5°C;

$F_{H,orp}$ = 71 m^2 - area of the outside walls (without the area of the windows);
F_{ok} = 2.5 m^2 - the area of the windows;
F_B = 7.5 m^2 - area of inside walls;
$B_H = B_B = 1 : (1/\alpha_B + 1/Y_B)$. Since $D_1 = R_1 s_1 = 0.36 < 1$ (the internal covering on wood fiber paneling) and $D_1 + D_2 = 1.5 > 1$ (where D_2 is the degree of solidity of the layer of heat insulation), Y_B is determined by the following formula:

$$Y = (R_1 s_1^2 + s_2) : (1 + R_1 s_2) = (0.06 \cdot 6.12^2 + 0.35) : (1 + 0.06 \cdot 0.35) =$$
$$= 2.59 \text{ kcal/m}^2 \cdot \text{hour} \cdot {}^\circ\text{C} ;$$

$$B_B = B_H = 1 : (1/7.5 + 1/2.59) = 1.93 \text{ kcal/m}^2 \cdot \text{hour} \cdot {}^\circ\text{C};$$

B_0 is the heat absorption of the windows; we will assume that it is equal to zero.

The required resistance to heat transmission of the outside walls is determined as follows:

$$R_3^{TP} = [9 + 1 : 0.05(21 + 40)] \cdot 73.5 : [1.5(1.93 \cdot 71.5 + 0.25 + 1.93 \cdot 7.5)\ 1] =$$
$$= 3.85 \text{ m}^2 \cdot \text{hour} \cdot {}^\circ\text{C/kcal}$$

Since the resistance to heat transmission of the window openings with triple glazing is 0.6$\text{m}^2 \cdot \text{hour} \cdot {}^\circ\text{C/kcal}$, and their total area in the room is 2.5 m^2, the resistance to heat transmission of the panels of the walls must be

$$R_{H.orp.} = (R_3^{TP} F_{ohc} - R_{ok} F_{ok}) : F_{H.orp} =$$
$$= [3.85 \cdot 73.5 = 0.6 \cdot 2.5) : 71 = 3.98 \text{ m}^2 \cdot \text{hour} \cdot {}^\circ\text{C/kcal},$$

and the required thickness of the heat insulation layer is:

$$\delta_{H3} = [R_{H.orp.} - (R_B + R_{\text{Д}.B.} + R_{c.\pi.} + R_H)]\ \lambda_{H3}\ b =$$
$$= [3.98 - (0.133 + 0.058 + 0.006 + 0.05)] \cdot 0.35 \cdot 1.1 = 0.14\text{m}.$$

The value of the resistance to heat transmission of the outside walls from the condition requiring that thermal stability to be provided in rooms during summer must be no less than the value required, R_{Λ}^{TP}, determined by Formula (61).

The maximum and average amount of solar radiation striking the outside surface of the wall (in the case of the Palatka settlement, the geographical latitude is 60°), and other values that enter into formula (62) to determine $A_{H.yc}$ are shown in Table 6.

Table 6. Calculated Values for Solar Radiation and the Times of Maxima for Latitude 60°

Orientation of Reflecting Structures	F_H, m^2	I_{max}, kcal/m^2·hour	I_{av}, Kcal/m^2·hour	Time of maximum, hours	ϕ
Southern	18	565	175	12	0.93
Eastern	9	671	178	8	0.66
Northern	18	195	70	18	0.92
Horizontal surface*	18	660	275	12	0.93

* The western wall of the apartment block abuts the service block.

The following were assumed in this calculation:

ρ =0.7 is the coefficient of absorption of the solar energy by a surface made of plexiglass, colored red;

At_H =7°C;

μ =1

Δt_B = ± 2°C.

Then

$$A^{\text{ю}}_{H.yc.} = [0.7(565-175:20+7]\cdot 0.93 = 19.2°C;$$

$$A^{B}_{H,yc} = [0.7(671-178):20+7]\cdot 0.66 = 16°C;$$

$$A^{c}_{H,yc} = [0.7(196-70):20+7]\cdot 0.92 = 10.5°C;$$

$$A^{rop}_{H.yc.} = [0.7(660-275):20+7]\cdot 0.93 = 19°C.$$

The required resistance to heat transmission of the wall is

$$R^{TP}_{\text{л}} = (19.2\cdot 18+16.9+10.5\cdot 18+19\cdot 18):[1\cdot 2(1.93\cdot 71.5+ +0.2.5+1.93\cdot 7.5)]=3.36\ m^2\cdot\text{hour}\cdot°C/\text{kcal}$$

(We are discussing a case in which the windows are protected against the penetration of solar radiation into the room);

$R_{H.orp}$ =(3.36·73.5−0.6·2.5):71=3.47 m^2·hour·°C/kcal;
the thickness of the layer of heat insulation of the outside walls is:

$$\delta_{n3} = (3.47-0.247)\cdot 0.35\cdot 1.1 = 0.12m = 12\ cm.$$

The calculated value for the resistance to heat transmission of the outside walls is R_3^{TP} , which is 3.85 $m^2 \cdot hour \cdot °C/kcal$, and the thickness of the heat insulation made of polystyrene is 14 cm.

CHAPTER IV THERMOPHYSICAL CONDITIONS OF THE CONSTRUCTION OF OUTSIDE WALLS AND THE PLANNING OF PARTS OF BUILDINGS

WALLS

The required operating characteristics of outside walls are determined by the required resistances to heat transmission, penetration of air and vapor, heat stability, the moisture conditions, and other thermophysical parameters, which must correspond to the climatic characteristics of the construction region and the purpose of the outside walls. All of these requirements must be met not only by portions of the blank walls, including the points at which the individual elements join, but also those areas which are located around the perimeter of openings, in corners, and places where plinths courses, facade and roof coverings, roofing, balconies, loges, etc., come together.

The diverse construction solutions in current house construction for outside walls, in the form of large complex elements manufactured in factories with a high degree of finish, including the coating and facing layers, requires that attention be paid to operational characteristics and conditions which will ensure a long service life for these walls.

Many modern industrial designs consist of multiple layers, with the physical properties of individual material layers being very different as a rule. In this connection, in order to ensure the required thermal, physical and operational characteristics, it is very important to specify the order of installation of the covering structural layers. The sealant must be located on the inside or outside surface of the wall or inside it. The specific characteristics of the installation of the sealant are important both from the standpoint of ensuring a favorable temperature distribution in the wall, and also ensuring that it has a normal moisture situation.

The material of the inside layer of the walls has a very great influence on the thermal stability of the buildings, since the variations of the temperature of the inside air are a result of a disruption of the stationary thermal regime.

Example. To determine the variations in the temperature of the air within a movable house (See Fig. 4) in the case

when the outside walls have an inside separating layer made of bakelitized panels and without separators, in other words with the inside surface of the wall covered only with a heat insulating material (foam plastic) covered by washable wall-paper (it need not be taken into account in the thermotechnical calculation). Assume that in both cases the thermal resistances of the walls are the same and are equal to 3.95 $m^2 \cdot$hours$\cdot$°C/kcal.

The calculated air temperatures are as follows: $t_{B} = 20°C$; $t_{H} = -50°C$; $A_{H} = 9°C$; $m = 0.1$; $\mu = 1$.

The heat absorption coefficient of polystyrene foam $s_{\pi} = 0.35$ kcal/$m^2\cdot$hours$\cdot$°C, while that for bakelitized panels is $s_{б} = 3.9$ kcal/$m^2\cdot$hours$\cdot$°C, with the coefficient of heat absorption of the inside surface of the wall with a separate panel (using Formula (46)) $B_{б} = 1.17$ kcal/$m^2\cdot$hours$\cdot$°C, while without the separating panel $B_{\pi} = 0.34$ kcal/$m^2\cdot$hours$\cdot$°C.

The coefficient of heat absorption of the surface of the floor in both cases is $B = 1.17$ kcal/$m^2\cdot$hours$\cdot$°C.

The amplitude of the temperature variations of the air in the room according to Formula (52) is determined as follows:

With an inside separator made of bakelitized panels:

$$A_{B}=[9+0.1(20+40)]\cdot 90:[3.95(1.17\cdot 70.5+0\cdot 2.5+1.17\cdot 18)]=3.3°C;$$

without an inside separator:

$$A_{B}=[9+0.1(20+40)]\cdot 90:[3.95(0.34\cdot 70.5+0\cdot 2.5+1.17\cdot 18)]=7.6°C$$

From this example we can see that in order to ensure the necessary thermal stability of buildings it is not possible to locate the thermal insulation on the inside surface of the building, directly facing the rooms, because the effect of heat insulating materials have a low level of heat absorption. When the thermal insulating material is located on the inside surface of a wall, it must be covered on the inner surface with a denser, more heat-conducting (and therefore more heat-absorbant) material.

In order to achieve the necessary thermophysical and operational characteristics for walls, it is preferable to seal them on the outside as a rule. However, in this case the heat insulating materials must possess sufficient resistance to climatic influences, excluding the development of cracks and

preventing the development of other kinds of possible damage to the outside surface of the wall.

When inclusions made of material with coefficients of thermal conductivity that is greater than the coefficient of thermal conductivity of the materials making up the structure of the wall are to be found in the outside walls, it is necessary to carry out additional calculations to determine the permissible geometric parameters for these inclusions. In this case the temperature on the inside surface of the wall at the place where the heat conducting inclusion τ_x is located must not exceed the temperature of the dew point of the air in the building:

$$\tau_x = t_{\text{в}} - R_{\text{в}}(t_{\text{в}} - t_{\text{н}})[R'_0 + \eta(R_0 - R'_0)]/R_0 R'_0, \qquad (63)$$

where R_0 is the resistance to heat transmission of the wall, $m^2\cdot$hours$\cdot$°C/kcal;

R'_0 is the resistance to heat transmission at the place where the heat conducting inclusion is located, $m^2\cdot$hours$\cdot$°C/kcal;

η is the coefficient which depends on the dimensions of the heat conducting inclusion (Figure 6), determined from Table 7.

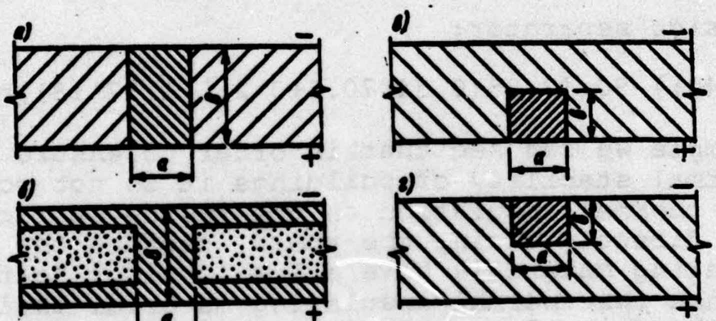


Figure 6. Forms of Heat-Conducting Inclusions
a - through; b - through, with heat-conducting surfaces; c - type which does not run all the way through, with a thermal side; d - type which does not run all the way through, on the cold side.

Table 7

Values for Coefficient η

Location of heat conducting inclusions (Figure 6)	Ratio a/b								
	0.02	0.05	0.1	0.2	0.4	0.6	0.8	1.0	1.6
a	0.12	0.24	0.38	0.55	0.74	0.83	0.87	0.90	0.95
b	0.07	0.15	0.26	0.42	0.62	0.73	0.81	0.85	0.94
c	0.25	0.50	0.96	1.26	1.27	1.21	1.16	1.10	1.00
d	0.04	0.10	0.17	0.32	0.50	0.62	0.71	0.77	0.59

The required total resistance to heat transmission of a structure at the point where the heat conducting (cold) inclusion $R_o'^{TP}$ is located, determined from the condition of non-permissibility of escape of condensate on the surface of the inclusion may be calculated by the formula

$$R_o'^{TP} = R_o\eta/(\theta + \eta), \tag{64}$$

where θ is the coefficient which characterizes the reliability of the structure against the appearance of condensate at the most dangerous point on the surface of the wall (Table 8.

If we compare the various versions of the heat-conducting inclusions, we can see that a drop in temperature on the inside surface of the wall will be minimal with inclusions with heat-conducting surface layers (type b in Figure 6), and also with inclusions that are located on the colder side of a wall (Figure 6, d), but in this case the temperatures will be distributed more uniformly, since the heat which spreads along the warmer surface of the structure promotes a homogenization of their values. On the other hand, a drop in temperature will be greater and sharper in the case of through inclusions with a rectangular shape (Figure 6a) and those inclusions which are located on the warmer surface (Figure 6c). It is not recommended to allow any heat conducting inclusions in walls in moist locations, so as to exclude the precipitation of a condensate from the inside air on the surface of the wall.

Table 8

Values for the Coefficient θ

Buildings	Temperature and humidity	R_O/R_O^{TP}							
		1.0	1.1	1.2	1.3	1.5	1.8	2.1	2.4
Residential	$t_B=18°C$; $\phi=55\%$	0.40	0.53	0.68	0.82	1.1	1.54	1.95	2.14
Public	$t_B=18°C$; $\phi=50\%$	0.50	0.64	0.81	0.95	1.24	1.72	2.15	2.58
	$t_B=15°C$; $\phi=60\%$	0.03	0.13	0.22	0.33	0.54	0.54	1.15	1.46

When reinforced concrete or metal frameworks are used for construction of buildings which are to be heated, their heat-conducting elements must be buried in the walls which enclose rooms which are to be dry when used. When using lightweight construction with an efficient heater, the walls must be located on the outside of the framework. It is necessary to keep in mind that for walls made of light concrete elements, heat-conducting inclusions can be formed when a structural solution with a high thermal conductivity is used.

However, we must point out that the construction of the outside elements of a building for northern regions is determined not only by the thermophysical requirements but, as we mentioned earlier, the conditions for organization and production of the construction and assembly work, which are extremely influenced by low temperatures, strong winds, high humidity and other negative atmospheric factors, which reduce the labor productivity and the quality of the construction, as well as increasing its cost significantly.

The principal requirements imposed on the economics of construction make it necessary to strengthen and lighten the construction, with extensive usage of light highly efficient sealers, which have a thermal conductivity coefficient between 0.04 and 0.18 kcal/m^2·hour·°C.

The need to reduce the cost of heat makes it advantageous to increase significantly the heat insulating properties of the walls by making the layers of efficient thermal insulating materials thicker relative to the minimum calculated value,

since this does not raise the cost significantly and makes the laminated structure of the walls heavier.

As completely prefabricated buildings made of sturdy elements become more popular, special attention should be given to the problem of butted connections between outside walls, since the strength and quality of the building depend primarily upon the life of the joints.

Vertical and horizontal junctions (butted surfaces) of structural elements making up outside walls must satisfy the requirements for necessary heat and sound insulation, impermiability to air and moisture, sufficient strength and service life of the steel supporting elements, and the minimum labor cost and high level of technological development of the products and assembly must be ensured.

The thermal protection of the butted connections is ensured by the temperature on their inside surfaces. Insufficient density of the joint reduces its heat-protective qualities, increasing the heat losses through the outside surfaces and creating an uncomfortable temperature condition in the rooms. However, reducing the temperature in the places where the walls come together is the reason why condensate forms on the inside surface of the walls.

Poor seals at the joints promote the penetration of rainwater into the structure of the building, which is a reason for the corrosion of the steel joints. Increased corrosion of the protected metal reduces the strength of the connections, causing crack formation in structures and thereby promoting further development of disruptive processes. Therefore metal assembly elements require a special anticorrosion protection.

The sealing of the joints, particularly in areas where there are strong winds, low temperatures and high humidity of the outside air is accomplished both on the outside and inside of the wall. On the outside, the joints are sealed with a mastic made of poroizol or izol, followed by obligatory coating with izol mastic and plugging of the cracks with synthetic mastic. The construction of these joints, filled with elastic fillers and mastics, must make it possible to repair and replace the outside facing. In order to protect the sealing material, which is destroyed by the influence of sunlight, it must be covered with a cement solution.

One way of protecting the vertical joints against the seepage of water which runs down the surface of the wall is vertical barricades or channels on the edges of the panels. In the

horizontal seams, a barrier must be provided in the lower-lying element, while quadrants and dripstones must be provided in the upper ones.

The greatest degree of water permiability can be seen in the horizontal joints where balcony plinths come together. Protection of these joints against the penetration of moisture is usually accomplished by means of a rain barrier, applying a hydrophobic coating to the outside surface of the panel. Particular attention must be paid to the proper fit of of water gutters against the roof, insulation of the cornices and deflectors, so that moisture does not get into the seams in the wall.

As a result of the filtration of cold air through butt joints, the temperature inside the building falls and its resistance to heat transmission decreases. The temperature through the cross-section of the building, taking filtration of cold air into account, can be determined by the formula

$$\tau_x = t_n + (t_в - t_н)(e^{cGR_x} - 1)/(e^{cGR_0} - 1), \tag{65}$$

where τ_x is the temperature in an arbitrary plane in the building, °C;

R_x is the thermal resistance of a portion of the wall from the outside surface to the arbitrary plane in question, with absence of filtration of air, $m^2 \cdot hours \cdot °C/kcal$;

c is the weight thermal capacity of the air, assumed to be equal to 0.24 kcal/kg;

$G = \Delta p / R_И$ is the amount of filtering air, $kg/m^2 \cdot hours$;

Δp is the pressure difference in the air with two opposite wall surfaces, mm water column.

$R_И$ resistance to air penetration of a wall, mm water column·hour·m^2/kg;

R_0 is the resistance to heat transmission of a structure as a whole, in the absence of filtration, $m^2 \cdot hour \cdot °C/kcal$;

The value of the resistance to heat transmission in the presence of through air filtration through a wall will be

$$R_{0.и} = (e^{cGR_0} - 1)/cGe^{cGR_0}. \tag{66}$$

When planning outside walls for large-panel buildings, particular attention should be given to filtration at the points where elements join. A small amount of cold air will penetrate through correctly designed and carefully sealed joints; under these conditions, the distribution of the temperatures at the junction point is considerably influenced by the thermal conductivity of the material composing the inner part of the panel. In the case of panels which do not have heat conducting inclusions near the joint, the minimum temperature at the surface of the structure at the contact zone may be established as a function of the value of the ratio of the thermal conductivity of the material composing the panel to the amount of heat which is required to heat the air passing through the joint, . Depending on the value of this ratio and the resistance to heat transmission of the panel, we can use Table 9 to determine the value of the dimensionless parameter $(t_B-\tau'_B)/(t_B-\tau_H)$, where τ'_B is the temperature in the vicinity of the junction, and therefore the temperature in the zone near the joint where the air is penetrating.

Table 9

Values of the Dimensionless Parameter $(t_B-\tau'_B)/(t_B-\tau_H)$ For Values λ/cG and R_0

λ/cG	R_0			
	0,8	1,0	1,2	1,4
0,04	0,58	0,55	0,53	0,50
0,05	0,56	0,54	0,52	0,49
0,1	0,52	0,49	0,47	0,43
0,2	0,43	0,37	0,34	0,32
0,3	0,38	0,36	0,33	0,31
0,4	0,35	0,30	0,27	0,25
0,5	0,32	0,28	0,24	0,22
1,0	0,25	0,22	0,18	0,17
1,7	0,23	0,19	0,17	0,13
2,0	0,21	0,18	0,15	0,125
3,0	0,20	0,17	0,14	0,12
4,0	0,19	0,15	0,13	0,115
5,0	0,18	0,14	0,12	0,11

If there is a heat-conducting inclusion in the vicinity of the air-penetrating joint, it will promote the temperature drop even more. We can assume that in this case the temperature at the surface of the joint $\tau'_{B.obu}$, which drops as a result of the penetration of the air and the increased thermal conductivity of the inclusion, will be

$$\tau'_{\text{в. общ}} = \tau'_{\text{в}} - (\tau_{\text{в}} - \tau''_{\text{в}}) = \tau'_{\text{в}} - \eta(\beta - 1)(t_{\text{в}} - \tau_{\text{в}}), \tag{67}$$

where τ_β is the temperature at the surface of the structure with an absence of air-penetrating conditions in it, and thermal conducting inclusions, °C;

τ'_β is the temperature at the surface of the air-conducting joint, with an absence of heat conducting inclusions, °C;

τ''_β is the temperature in the presence of a heat conducting inclusion, without penetration of air, °C;

$\beta = R_O/R_O$ is the ratio of the resistances to heat transmission at the point where there is no inclusion present and within the limits of the latter.

Example 1. To determine the temperature on the inside surface of a wall with through filtration of cold air and its decrease in resistance to heat transmission. The calculated temperatures of the air are as follows: t_β=18°C; $t_н$ =-26°C. R_O of the wall is 1.11 m^2·hour·°C/kcal; Δp=2.21 mm water column; R =0.2 mm water column·hour·m^2/kg; G=2.21:0.2=11 kg/m^2·hour.

The temperature on the inside surface of the wall according to Formula (66) will be

$$\tau_{\text{в}} = -26 + (18 + 26)(e^{0,24 \cdot 11 \cdot 0,98} - 1) : (e^{0,24 \cdot 11 \cdot 1,11} - 1) = 4,7\ ^\circ C$$

(0.98 is R_X equal to R of the structure of the wall plus R).

The value of the reduced resistance to heat transmission of the wall with through filtration of cold air according to Formula (66) will be:

$$R_{\text{о. и}} = (e^{0,24 \cdot 11 \cdot 0,98} - 1) : 0,24 \cdot 11 e^{0,24 \cdot 11 \cdot 0,98} = (18,92 - 1) : 2,65 \cdot 18,92 = 0,36\ \text{м}^2 \cdot \text{ч} \cdot {}^\circ\text{C/ккал},$$

where the value is almost three times smaller than R_O of a wall, equal to 1.11 m^2·hour·°C/kcal.

Example 2. To determine the temperature on the inside surface of a panelled wall at a junction zone, taking into account the penetration of air and the presence of heat conducting inclusions. The panels are made of reinforced concrete material, sealed with keramzite concrete. The

calculated air temperatures are as follows: t =18°C; t =-32°C; the resistance of the joint to the penetration of air R = 4 mm water column·hour·m^2/kg; the difference in air pressure on two opposite surfaces of the wall Δp=2mm water column, the resistance to heat transmission of the panel R_o=1.2 m^2·hour·°C/kcal; the resistance to heat transmission along the heat conducting inclusion R_o=0.77 m^2·hour·°C/kcal; the ratio $R_o/R_o=\beta$=1.20:0.77=1.55; a/b=0.15;0.23=0.65, and the value of the coefficient η according to Table 7 is 0.75.

The temperature on the inside surface of the panel some distance from the joint according to Formula (15) will be

$$\tau_{в} = 18-[(18+32):1.2]\cdot 0.133=12.4°C,$$

and the temperature $\tau_{в.обш}$ at the area of the junction, taking into account the penetration of air and the presence of a heat conducting inclusion, according to Formula (67) will be

$$\tau_{в.обш} = 9.5 - 0.75(1.55-1)(18-12.4) = 7.2°C,$$

which is below the dew point for residences. Consequently, the joint in question will require additional sealing.

In the vicinity of the contact between the walls and the coverings between the floors, it is important to provide additional sealing of the horizontal junctions, and when there are hollow reinforced concrete members, resting on the outside walls, the openings in these members must be covered with blocking elements to avoid filtration of cold air through these spaces, which is a reason for low temperatures on the surfaces of the coatings.

Homogeneous - single-layer - panels, made of light concrete and protected on the inside and outside with textured or individual layers, are characterized by lack of thermal conductivity, without any cold inclusions, a uniformity of distribution of temperatures and rather high operational characteristics; they conform in every way to the requirements for outside coverings for buildings with normal humidity conditions. When applied to the inside surface, such reliable protective layers can be used in moist buildings with low temperatures. The negative characteristic of homogeneous light concrete panels is their initial high moisture content when constructed from materials that dry slowly. This serious shortcoming is associated with unfavorable drying conditions resulting in crack formation especially in the outside areas of the structure.

Two-layer panels with ribs along their edges have heat-conducting - cold - inclusions, which accounts for the inhomogeneity of the temperature distribution and therefore causes a situation in which the structure of the panels must be tested in order that temperature drops do not occur on their inside surfaces down to the dew point.

Three-layer panels, like all multi-layer wall materials, require careful attention to the location of the material layers and a sharp limitation of their thermophysical functions.

In designing three-layer as well as two-layer panels, it is necessary to take into account the various strengthening ribs, metal anchors or other elements for linking the inner and outer layers of material, requiring that such solutions be checked from the standpoint of their heat protective properties.

Sealing or moistening these products in the cementing process, hot-moisture treatment or other operations involved in the production of panels, as well as the comparatively low viscosity of the layer of heat insulating material which is placed between the two structural elements, resulting from other random factors, can considerably reduce the heat insulating properties of a panel, which depend upon the state of the effective sealers. It is therefore necessary to increase the thermal resistance of the heat insulating layer by 20% according to the standards.

To protect the outside walls against moisture due to condensation of water vapor from the inside air inside them, provision must be made for vapor insulation, in view of the fact that in multi-layered structures with a layer of efficient thermal insulation the ratio of the resistance $R_{в.т.}$ for the inner part of the structure to the $R_{н.п.}$ of the outside part of the structure in buildings with a dry humidity regime must not be less than 1, for normal humidity conditions not less than 1.2, and for areas with a moist wet regime no less than 1.5. However the same ratio must be observed in single layer construction.

COVERINGS AND FLOORS

According to the thermotechnical requirements, floors can be divided into three groups:

1) Floors of heated buildings with high operational requirements (in residences, childrens institutions, hospitals and so on), where it is anticipated that there will be con-

tact with the floor either with shod or bare feet;

2) The floors of heated buildings with normal operating requirements and temporary occupation by people (in public (including administrative buildings), movie theaters and so on);

3) The floors of unheated buildings with low operational requirements, as well as buildings where the air temperature is above 23°C.

Hygienists have established that comfortable conditions require that the temperature of the feet not be below 27°C. Therefore the temperature of the surface of the floor and the coefficient of heat absorption of the material covering the floor must be selected so that the temperature at the point of contact between the feet and the floor is not below this limit.

To avoid overcooling of the feet, floors must be built so that the amount of heat absorbed by the floor does not exceed the loss of heat to the foot. The construction of floors without adequate attention to their hygienic and thermotechnical properties results in a sharp deterioration of the microclimate in the room, and the systematic cooling of the feet is a reason for disruption of thermoregulation of the organism and often causes people to catch cold.

As field tests of apartments on the first floors of buildings with breezeways beneath the floor and movable buildings have shown, when these buildings are mounted on skis or platforms, the temperature of the surface of the floor is very low and the temperature differential between the air in the room and the surface of the floor is 8 to 10°C, even when the outside air temperature is much less than the calculated level. The principal reason for this is not in the low thermoprotective qualities of the structure but the conditions relating to heat exchange at their surfaces.

The heat exchange at the surface of a building is described by the following equation:

$$q=(t_{\text{в}}-\tau_{\text{в}})/R_{\text{в}}=\alpha_{\text{в}}(t_{\text{в}}-\tau_{\text{в}}). \tag{68}$$

The coefficient of heat absorption (heat exchange) on the inside surface of a building $\alpha_{\text{в}}$ is the sum of the coefficients of the convective $\alpha_{\text{к}}$ and radiant $\alpha_{\text{л}}$ heat exchange:

$$\alpha_{\text{в}}=\alpha_{\text{к}}+\alpha_{\text{л}}, \tag{69}$$

and formula (68) can be written as follows:

$$q = (\alpha_к + \alpha_л)(t_в - \tau_в) = \alpha_к(t_в - \tau_в) + \alpha_л(t_в - \tau_в). \quad (70)$$

The value for radiant heat flux per unit of surface of a structure is determined by the formula

$$q'_л = \sum \varepsilon c_0 \varphi [(T_{в.о}/100)^4 - (T_{в.п}/100)^4] =$$
$$= \sum \varepsilon c_0 \varphi b_t (\tau_{в.о} - \tau_{в.п}), \quad (71)$$

where ε is the derived coefficient of radiation of the surface of the structure relative to the other walls in the building;

c_0 is the coefficient of radiation of an absolutely black body, equal to 4.96 kcal/m^2·hour·°C;

Φ is the coefficient of radiance of a surface of a structure with the surfaces of other buildings;

$T_{B.O.}$, $\tau_{B.O.}$ are the temperatures of the inside surfaces of a building, expressed in K and °C respectively;

$T_{B.\Pi.}$, $\tau_{B.\Pi.}$ is the temperature of the inside surface of the wall in question, in K and °C respectively;

b_t is the temperature coefficient.

Then the coefficient of radiant heat exchange will be determined by the following expression:

$$\alpha'_л = q'_л / (\tau_{в.о} - \tau_{в.п}). \quad (72)$$

In building practice, however, determination of the radiant heat flux at the surface of a building (in the particular case of the surface of a floor) is determined by the formula

$$q_л = \alpha_л (t_в - \tau_{в.п}), \quad (73)$$

whence

$$\alpha_л = q'_л / (t_в - \tau_{в.п}), \quad (74)$$

where q is the total radiant heat flux per unit of floor surface, kcal/m^2·hour·°C.

This assumption was made on the basis of the opinion that in a building, in addition to one outside wall, for which $\alpha_л$ is determined, all the other walls are inside walls and have a temperature which is equal to the air temperature.

In this case, when the temperature of the outside structure differs from the temperature of the building (which is always the case when there are several outside walls, including the floor and ceiling), the coefficient α_{Λ} which is calculated by Formula (74) is only a conditional coefficient of radiant heat exchange, whose value must be determined for each wall separately.

As we mentioned earlier, the temperature drop between the air in the room and the surface of the floor must not exceed 2°C, and the temperature difference between the air and the surface of the ceiling must not be more than 4°C, or the difference between the air and the surface of the outside walls must not be more than +6°C. Consequently, the floor must have a calculated temperature which is higher than that of the other walls. Therefore the surface of the floor radiates heat to the surfaces surrounding it, while at the temperature values which we have adopted the convective heat flux is directed toward the surface of the floor. Although the heat fluxes operate in opposite directions, according to equations (68) and (70) they are proportional to the same positive difference in temperature $(t_в - \tau_{в.п})$, and the coefficient of heat exchange $\alpha_в$ is determined as the sum of the coefficients α_{Λ} and $\alpha_к$. From this it follows that in determining the total coefficient of heat exchange for the inside surface of a wall expression (69) will be valid only when the convective and radiant heat fluxes coincide in direction.

The coefficient of radiant heat exchange α_{Λ} depends upon the temperatures, areas, reflectivity and position of the mutually radiating surfaces. Consequently, in different rooms α_{Λ} of the surface of the floor will have different values.

The coefficient of convective heat exchange $\alpha_к$ at the surfaces of walls, at the ceiling and at the floor will differ even for a given room. Since the temperature of the air in the room exceeds the temperature of the floor, the convective component of the heat flux at the floor with convection without artificial stimulation will tend toward a minimum value.

According to [1], for a horizontal cooled surface

$$\alpha_к = \sqrt[3]{\Delta t^н}. \quad (75)$$

Since the temperature drop $\Delta t^н$ for the floor is assumed to be 2°C, α_K = 1.26 kcal/m^2·hour·°C.

Example. Let us examine four rooms, which are located in buildings with breezeways beneath them and are characterized by a ratio of the areas of the inside $F_в$ and outside $F_н$ walls. For each of these, let us determine the coefficient of heat exchange at the surface of the floor $\alpha_в$. We will assume that the air temperature in all of these rooms is the same ($t_в$ =20°C), and all of the walls have on their inside surfaces the calculated values of the temperature (for the wall $\tau_в$ = 20 - 6 = 14°C; for the ceiling $\tau_в$ = 20-4= 16°C; for the floor $\tau_в$ = 20-2= 18°C, for the inside wall $\tau_в$ = $t_в$ = 20°C). The dimensions of these rooms are 6X3X2.7 m. The area of the floor $F_п$ =18 m². The calculations are shown in Table 10. Under these conditions all of the heat exchange coefficients (α) are obtained with a plus sign. The direction toward the surface of the floor is assumed to be the positive direction of heat flux.

Table 10. Calculated Values for Coefficients of Heat Exchange and Heat Fluxes at the Surface of the Floor in Various Rooms

Characteristics of the room	Area of Surface, m²		Coefficients of heat exchange at the surface of the floor, kcal/m²·hour·°C			Heat fluxes at the surface of the floor, kcal/m²·hour		
Intermediate room on the second floor of a multi-story building (one window)	26.1	58.5	3.06	1.26	4.32	6.12	2.52	8.63
Corner room on the second floor (two windows)	42.3	42.3	0.34	1.26	1.60	0.68	2.52	3.20
Corner room of a one-story house (two windows)	60.3	24.3	2.5	1.26	1.24	-5.0	2.52	-2.48
Independent small house (two windows)	84.6	-	7.1	1.26	5.84	-14.2	2.52	-11.68

Using the results of this calculation, let us consider the heat balance at the surface of the floor in these rooms. We will assume that the calculated temperature of the outside air is -50°C, and the air temperature in the rooms and the temperature at the surfaces of the walls remain constant. The required resistance to heat transmission of the construction of the floor according to SNIP II-A.7-71 must be at least 4.65 $m^2 \cdot hour \cdot °C/kcal$. The specific heat flux through the wall in this case will be

$$q_R = (t_в - t_н)/R_0 = (20 + 50) : 4{,}65 = 14{,}9 \text{ ккал/м}^2 \cdot \text{ч}.$$

On the basis of the heat balance at the surface of the floor, the following equation must be satisfied:

$$q_R = q_к + q_л \qquad (76)$$

However, substituting the calculated values for the specific heat fluxes calculated in Table 10 into equation (76), for the first room we will have 14.9>2.52+6.12, i.e. the amount of heat which can be transmitted through the wall exceeds the amount of heat which is applied to the surface of the floor. In order to ensure that the heat balance at the surface of the floor will exist, we must increase the resistance to heat transmission of its construction, which must be 7.7 $m^2 \cdot hour \cdot °C/kcal$, in other words 1.7 times greater than required according to SNIP.

For the second room, the resistance to heat transmission of the floor (for tabular values of $\alpha_л$ and $\alpha_к$), it is necessary to increase it to a value of 21.6 $m^2 \cdot hour \cdot °C/kcal$, in other words by 4.8 times more than standard.

In the third and fourth rooms, the sum of the convective and radiant heat fluxes (Table 10) has a negative value, i.e. the floor must lose heat toward the room. Consequently, in order to retain the given values for the temperature, it is necessary to establish at the floor the heat source (to heat the floor) or to increase the convective component of the heat flux to its surface.

For these rooms, equation (76) is valid for the following values $\alpha_к$: for the third room - $\alpha_к$ =9.9 $kcal/m^2 \cdot hour \cdot °C$; for the fourth $\alpha_к$=14.5 $kcal/m^2 \cdot hour \cdot °C$. These values for the coefficients of convective heat exchange will be ensured with air mobility at the surface of the floor on the order of 1-2 m/second. However, the mobility of the air with a velocity exceeding 0.2 m/second is not allowed in residences.

The reduction in the radiant heat loss from the surface of the floor can be achieved by increasing the temperature at the surface of the surrounding walls by increasing the resistance to heat transmission, which is in agreement with the requirements for thermal comfort in residences (see Chapter II). However if the outside walls and floor have the same temperatures, for all practical reasons we can conclude that there is no heat exchange between them and consequently α_{Λ} would be equal to zero. However, even in this case the coefficient of convective heat exchange at the surface of the floor will be 7.5 kcal/m^2·hour·°C, and the rate of convective flow will be at least 0.5 m/second, which is also greater than the standard values for air mobility.

The results of this analysis and the field tests of residences indicate that the only reliable way of ensuring normal temperature conditions on the first few floors of buildings with breezeways beneath the floors, especially in northern regions, is artificial heating of the plinth courses. To heat the floors, hot water, hot air or electricity can be used. The choice of heater in each individual case must be made on the basis of technical and economic factors and calculations.

When using heat given off by individual pipes in a system for heating a building with water, the non-insulated pipes are laid beneath the floor itself, with provision of access holes for free access to the pipes. In order to increase the heat given off by the pipes, ribs are often mounted on the smooth pipes.

When using air for heating, the hot air is fed into the space beneath the floor, beneath the floor itself and the surface covering it (Figure 7). The absence of a heat carrier, which would be endangered by freezing, does not pose any danger that the system will break down if the heat is shut down, regardless of what the outside conditions may be. In some cases, this method of heating floors can be combined with the ventilation system for the building.

However the most promising approach as far as hygienic and technical characteristics is concerned, as far as the possibility of extensive application at the present state of the art is concerned, is the heating of floors using low temperature electric panels or electric cables (Figure 8), which are laid directly in the floor. The unquestionable advantage of electric heating is the possibility of automatic regulation of the level of heat output and consequently the maintenance of a constant floor temperature which is very

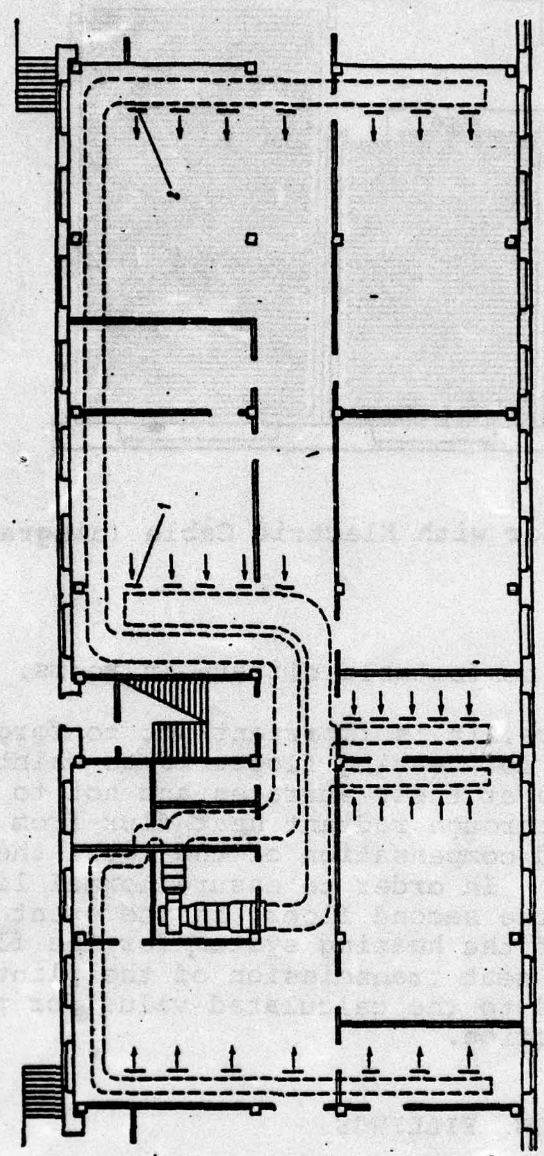


Figure 7. Heating a Floor with Air (Plan of Air Ducts)
1 - network with moveable dimensions 300X150 mm;
2 - ditto, 300X200 mm.

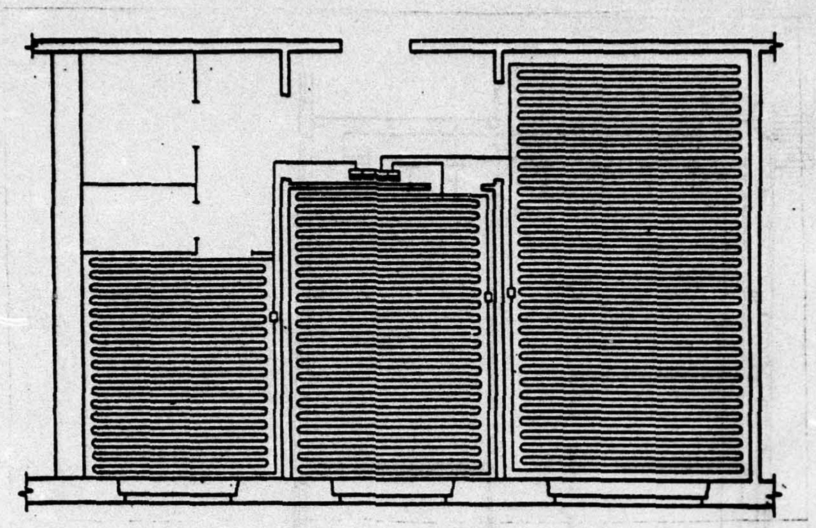


Figure 8. Heating a Floor with Electric Cable (diagram of cable layout)

important for keeping a comfortable climate in rooms.

When designing hot floors, it is important not to forget that the principal goal for heating floors is to maintain comfortable temperatures at their surfaces and not to create thermal comfort through radiant heat flux from the surface of the floor and compensation of the total thermal losses by the building. In order to ensure normal living conditions in rooms on the second floor, in the event of an emergency shut-off of the heating system for the floor, the total resistance to heat transmission of the plinth covering must correspond to the calculated value for the given region of construction.

WINDOW FILLINGS

In additbn to a number of general requirements relating to the outside walls of buildings such as strength, service life, industrial characteristics, economy, architectural design, windows are subjected to requirements that follow from their structural features and functional purpose:

- Ensuring the necessary thermal protection against the influence of low temperatures of the outside air, as well as being subject to hermetic sealing, guaranteeing against drafts, freezing and sweating;

- Light-technical requirements, which amount to ensuring that rooms have normal illumination by daylight;

- The required sound insulation for rooms against outside noise.

Windows are the parts of a wall which allow the most amount of heat to pass through. The values of the coefficients of heat transmission for glazed openings range from 1.5 to 5.0 kcal/m^2·hour·°C, depending on the number of panes. The heat losses through the windows, regardless of the relatively small size of the latter, amount to 30-50% of the total heat losses from the building.

The type and nature of the window casings to a large degree influence the thermal protection of buildings against the ability of cold outside air to penetrate through cracks in windows which open, as well as around the edges of the glazed areas. The high degree of infiltration and the considerable negative radiation of man to cold surfaces of glass, which form protection against drafts, makes it impossible to use areas of the room which are near the windows. This situation is particularly serious in northern regions, where, during the long polar night, low temperatures, strong winds, and snow storms occur and the heating season lasts 10-11 months.

Due to the low temperature of the glass on its inner side a layer of cooled air forms, which has a lower temperature than the air in the room. The cooled air moves inward and forms a constant flow which is felt as a draft. The best and most widely used method of protection against this draft of cold air is to locate the heating devices directly beneath the windows. The hot air rising from the device moves over the source of the cold air, the two flows mix, and the draft is eliminated.

A slight decrease in the uncomfortable conditions during the winter period with considerable amounts of glass area can be achieved by window curtains that can be drawn completely over the glass and form an air layer between the curtain and the glass. However, it must be kept in mind that the curtain prevents the access of warm air to the window, thus leading to a sharp drop in the temperature on its inner surface, with sweating of the glass and formation of frost.

The condensate can be formed on the inner surface of outside glass which is colder in the event of an insufficient seal of the inner layer, since the temperature of the glass is below the dew point for air which is penetrating from the room. The condensate is undesirable because it damages the

light transmission to the room and also moistens the casement, reducing its thermal protective qualities and causing rotting of the wood in many cases. In order to prevent the penetration of air into the space between the panes of glass from the room side and to prevent the condensation between the window frame and the inner glass a sealer can be applied, and the slot-like openings between the window frame and the outside glass can be eliminated. The presence of openings promotes not only removal of the moist air from the space, but also the rapid drying of wet parts of the window.

In recent years, there has been a tendency toward a considerable increase in window and other open areas in the outside walls of buildings and public structures. Often a conflict arises between the specialists on illumination and heat engineering specialists, since the desire of the former to ensure the greatest amount of light in the building forces the heating engineers to find ways of warming the building better. As field tests in regions with a harsh climate have shown, the requirements of economy and the necessary heat comfort determine the advisability of extreme limitation of the area of light spaces.

In the continental regions of the North with a very low temperature of the outside air in winter and a relatively low amount of wind during the whole year directed against the windows, it becomes necessary to have an increased level of heat production against the cold effects of the outside air. In coastal regions, in regions with strong winds, high humidity, and a lack of severe frost in winter, it is necessary to pay particular attention to the hermetic seal of the window frames so as to avoid the influence of penetration of cold air upon the temperature regime of the building. Triple and quadruple glazing of the windows is recommended, so that the temperature at the surface of the innermost glass does not drop below +6°C at the calculated outside temperature.

We must keep in mind that the multiple glazing simply causes an increase in the resistance of the glass to heat transmission. However, a decrease in the air transmission can only be achieved by increasing the aerodynamic resistance of the structure and the plugging of leaks. In order to reduce the heat losses it is recommended that window frames and casings for windows be designed from dry wood. The quality of the filler for the window structure increases its thermal resistance and considerably increases the service life.

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PROTECTION AGAINST HEAT LOSS AND MECHANICAL EQUIPMENT OF BUILDI--ETC(U)
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ROOFS

Roof design can be divided into the attic type, with an attic that runs all the way or part way through and combined roofs (without an attic): nonventilated continuous construction. The ventilated type have an air layer or individual channels. In many cases the attic space forms a separate technical stage, in which engineering pipes and equipment are located. Therefore the attic roofs and the coverings for the upper stories, as well as the combined roofs, must be provided with the necessary thermophysical and operational characteristics which must be taken into account in planning.

The moisture content of the materials in the roof is one of the most important factors that governs their service life and heat insulation properties. A constant source of humidity is the moisture that enters in the form of vapor from the air in rooms during the cold season of the year. The transfer of water vapor through the attic can lead to considerable moisture development there and losses of the required thermoprotective qualities of design. However, when building adequate internal vapor insulation and providing free escape for moisture from the heater, the moisture of the heat insulation layer is usually not taken into account and the roof retains its good operating characteristics for many years.

As field tests have shown, unsatisfactory conditions of combined roofs, especially during the first few years of operation, can be explained mainly by the high initial (structural) humidity of the structural materials. In many buildings the upper stories show dampness of the ceilings, development of mold on them and during severe frosts freezing takes place, so that icicles appear. In buildings with combined unventilated roofs, the dampness appears in the form of drops of moisture over the entire surface of the ceiling. It is characteristic in these cases to see a temperature drop and a rise in humidity of the air in the apartments on the upper floors of a building.

Table 11 shows the results of a study of the conditions in reinforced concrete roofs of buildings that were built by the Leningrad DSK. The laboratory investigations of samples of heaters taken from roofs in a construction area during assembly and from the roofs of buildings in use, show that the average specific humidity is 3-4 times greater than the humidity allowed by the standards.

An analysis of the results of this study confirms that the amount of structural moisture in the heater of the ventilated roofs decreases every year and after two to three years reaches a normal level, while the humidity for the heater of non-ventilated roofs not only fails to decrease but even increases.

Table 11. Average Specific Humidity of Heater in Investigated Roofs (in %)

Type of Roof	Heater	Structural	After 1 year of operation	After 2 years of operation	According to SNIP
Unventilated	Foam concrete, = 500 kg/m^3	30-32	30-35	38	8-10
Ventilated	Slag, = 900 kg/m^3	19-25	16-18	8-10	4-6
Ventilated	Crushed rock, gas concrete, = 400 kg/m^3	18-20	10-12	10	10

When we examined roofing paper which was waterproof and which had been applied to unventilated combination roofs, we failed to find any moisture beneath the upper layers, but there was a condensate beneath the lower layer, in the form of drops of water; the foam concrete was wet.

The average humidity of the heat insulating material after two or three years of use reaches 40-45% in comparison with the standard 8-10%. The absolute amount of moisture which passes through 1 m^2 of roofing material amounts to 30-40 kg on the average and in some cases reaches 50-60 kg or more. The condensate which gathers beneath the water-insulating material in summer, when the roof is heated by the sun, changes into steam which exerts a positive pressure on the waterproofing cover from below, tearing it free from the base and forming local blistering which leads to rapid destruction of the covering.

The increase in humidity of the thermoinsulating material as a rule increases the value of the coefficient of thermal conductivity and reduces the total resistance of the barrier to heat transmission. In the graph in Figure 9 we see the change

in the coefficient of thermal conductivity of cellular concrete with a specific gravity of 500-600 kg/m^3 as a function of the specific humidity of the material at positive and negative temperatures. There is a particularly sharp increase in the thermal conductivity at negative temperatures. During winter therefore the wet structures exhibit minimum resistance to heat transmission, promoting freezing of roofs and a drop in the temperature in apartments on the upper floors. Hence, the device of unventilated roofs, especially in the North, can only be used when the following conditions are met at the same time:

- initial (structural) moisture of the materials used in construction must not exceed the standard;

- possibility of accumulation of moisture during construction and use must be excluded;

- the relative humidity of the air in the building must not exceed 60%.

If the structure of the roof remains dry, over a long period of time there would be no need for considerable repair work and the high temperature-resistive qualities would be maintained.

In ventilated designs for roofs, the air layers and channels must be placed beneath the temperature insulation or in its upper areas, whose more pronounced heating during summertime promotes accelerated drying. The thickness of the layers and the diameter of the channels must be at least 50 mm, and the distance between channels must be at least 150 mm, but no more than two-thirds of the maximum thickness of the covering. The ventilated spaces and channels must communicate with the outside air through openings in the lengthwise outside walls. The total cross-section of the channels and accessory openings in each of the walls must be at least 0.001 of the area of the horizontal projection of the roof. In all cases, the access-egress openings must be closed by a metal screen or a grid with openings measuring 20X20 mm.

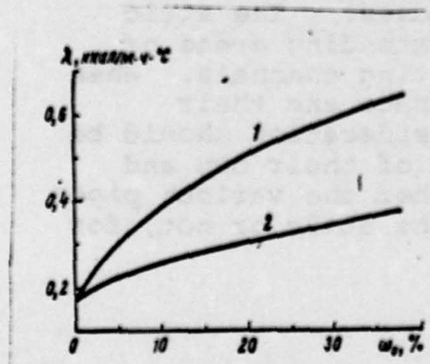

Figure 9. Graph showing the change of the coefficient of thermal conductivity of cellular concrete: 1 - with negative temperatures; 2 - with positive temperatures.

When designing attic roofs it is necessary to try to ensure that the temperature and humidity regime of the air in the attic rules out the development of biological and corrosion processes, premature breakdown of parts of the roof, coverings and structural parts of the buildings, formation of ice on the roof.

With unfavorable temperature and humidity conditions in the attic space, drops of moisture will accumulate on the inside surface of the roof, and, running down the inside, will make it wet. As a result, the thermoprotective qualities of the roof cover will be considerably deteriorated.

A particularly unfavorable temperature and humidity situation can be seen during the first few years of use of a building, since as a result of the high humidity of the materials and the wall construction when the building is erected, the relative humidity in the attic reaches 100%. Therefore, during the first few years of use of such buildings, it is particularly important to ensure that there is rapid drying of the walls of buildings with attics.

The level of atmospheric humidity in buildings with attics can be lowered by active air exchange which, as in the case of other buildings, is accomplished under the influence of wind and temperature heads. Sufficient ventilation for the attic space during the winter is ensured only when the intake and exhaust openings in the active zones of aerodynamic heads have different sizes, in other words on the wind and lee sides. The greater the temperature head, the more active the ventilation. The maximum air exchange in the attic space can be ensured by locating the ventilation openings at two levels: the intake in the zone of positive values for aerodynamic coefficients, in the cornice area of the wall, and the exhaust opening in the area of negative values of the coefficients, along the edge of the roof.

In the attic areas of residences in many cases there are distributing pipes for the heating system, plenum chambers for ventilation systems, exhaust ventilation shafts and rooms built into the building for special purposes. The attic and roof are intersected by vertically extending areas of sewer standpipes and blocks of smoke-venting channels. When these devices are located in the attic space and their structural solutions are worked out, consideration should be given to the conditions and requirements of their own and the attic location. Regardless of whether the various pipes and engineering devices are located in the attic or not, for

reasons of convenience in examination and repair of the roof, the attic should have a height of at least 0.7 m at its lowest point and at least 1.2 m at the highest.

The plenum chambers for the ventilation system, built into residences with attics, are located in the attic up against the inside walls, where the vertical ventilation channels are located.

The walls of these plenum chambers must be carefully heated, with careful sealing of the connecting pipes. It is necessary to heat the walls so that condensation will not develop on their inside surfaces and in order to reduce the heat loss between the plenum chamber walls and the air in the attic. The hermetic sealing of the joints is important in order to prevent air exchange through them.

Exhaust chambers for air with a relative humidity up to 60%, mounted in the attic space, is recommended for construction from plaster-slag panels 40 mm thick with an air layer 40 mm deep or a porous plaster-slag panel 100 mm thick. In the case of air with a high relative humidity it is necessary to make boxes out of double slag-concrete panels 100 mm thick, with an air space measuring 50-60 mm or out of concrete blocks with walls 100 mm thick and round spaces measuring 50-60 mm.

The attic coverings must be sufficiently well sealed so that the hot air in the rooms on the upper floors cannot penetrate into the attic. For this reason, it is important to have a good seal on the seams in the covering, preferably using planks cut to fit the room.

Roofs, depending on the properties of the material and their resistance to the actual meteorological factors, have different service lives. Roofs that are made of roofing material, roofing steel or other materials that are impermeable to moisture, are subject to gradual breakdown more rapidly than the supporting structure of the roof, so that the limiting state of destruction, corresponding to the loss of their standard operating properties, is determined not by a gradual loss of strength of the structural layers of the building but a more rapid loss of their impermiability to moisture.

Maximum service life distinguishes those roofs which are made out of galvanized sheet metal and old steel, as well as the multi-layered roofing material with more than four layers, with a protective layer of sand and gravel. These roofs do not require periodic repairs and do not change their characteristics over a long period of time under the influence of meteorological factors.

In addition to the number of layers and the presence of a protective layer, the service life of roofing material depends upon their adhesion to the surface. Sufficient adhesion of hydrophobic mastic to the subjacent surface can be achieved only when the base is dry and has been prepared for glueing. The best results in this regard are obtained by using a system in which the first layer of roofing material is glued under factory conditions, making large-scale coating elements. This rules out unfavorable effects of weather and has the considerable efficiency associated with methods of preliminary processing of the surfaces with hydrophobic compounds and emulsions, which are soaked into the surface layer of the base.

The most rapid destruction of roofs takes place in places where is a periodic intensive exposure to moisture and freezing. With a shallow slope to the roof, water stays on it for a long time so that the upper layer eventually becomes soaked and then dries out; these phases alternate and processes of decomposition begin in the roofing material. It is therefore particularly important to ensure that the water runs offthe roof smoothly.

In Northern regions, the rain and melt water must be removed from the roof by an inside water drain. It is not possible to attach gutters within or near the outside walls because they might freeze. In order to combat the freezing of the water runoffs it is recommended that the upper part of the pipe be heated (beneath the lower surface of the roof), using electrical heat for the purpose.

The ventilation shafts, exhaust sewer standpipes, television antenna masts and supports for radio and power lines on roofs must be combined into a multi-purpose unit which should be made so that it can be disassembled.

CHAPTER V ENGINEERING DEVICES

GENERAL INFORMATION

The most important element of building construction in the North consists of central heating systems, which are subjected to severe stress on their operational reliability. As a consequence of the considerable heat losses from buildings, as well as the sharp variations in the temperature of the outside air and the effects of wind, heating systems must have considerable flexibility during operation. From the hygienic standpoint, it is advantageous in the northern regions to have systems with a predominance of radiation components in the heat loss from heating devices.

At the present time, residences and public buildings in the North as a rule use water-type heating systems of various kinds. The most advantageous solutions include forced water systems, particularly the low pressure variety, in which the distributing pipes are laid beneath the building. This solution allows the best utilization of the heat.

Use of heating systems with wall controls for their heat output, employing automatic devices, is recommended. Systems of this kind make it possible to react under operational conditions to changes in heating requirements as a function of the action of the wind and solar radiation.

Electrical systems for heating buildings have considerable advantages over other types thanks to their flexibility and the possibility of regulating the heat output. These systems are not subject to freezing, contain little metal, are highly work-intensive and come largely preassembled, while allowing considerable variation in terms of the amounts of convective and radiant heat output. However, they are still not in wide use. Air-type systems are of interest for buildings in the North, since they are not subject to freezing, especially in their cheapest form, the air-curtain, which prevents considerable heat losses in contrast to noncirculating air systems. However, in view of the difficulties that arise in distributing the air through ducts and sealing them, this system has not yet become widely used and has even failed to get beyond the experimental stage.

Another area of considerable importance is the heating of the floors of residences, which are above breezeways. Some

technical recommendations regarding the heating of floors are given below.

The thermal and hydraulic calculations for heating systems must be based on the conditions for maximum automation of production and assembly of the individual elements.

An important engineering factor in residences is ventilation. As we know, the inside air in buildings is less satisfactory than outside air as far as its sanitary and hygienic properties are concerned, especially in buildings that use gas. Deterioration of the air takes place not only in the kitchen, but in bathrooms where gas water heaters are used, although the products of combustion in this case are vented through the chimney. Accumulation of harmful substances in the kitchen and bathroom is reflected in the living areas as well.

These negative phenomena can be eliminated by proper ventilation of the rooms using an organized type of air exchange. This is particularly important under northern conditions, where the population has to spend a great deal of time in enlosed areas because of the harsh weather and climate conditions.

In modern residences, the ventilation system operates on the basis of natural exhaust of used air through special exhaust ducts and the natural influx of fresh air from outside through cracks in the walls or through special intake openings that are mounted on the outside walls.

The ventilation systems used for residences can be of the following types:

With exhaust ducts in each room and in those areas which are used for sanitary and cooking purposes in the apartment, with no intake openings;

With exhaust ducts only in the bathroom and kitchen, with no intake openings;

With intake openings in the walls of living areas and exhaust ducts in the bathroom and kitchen;

With intake openings and exhaust ducts in the living area and exhaust ducts in the bathroom and kitchen.

As a result of many years of investigation it has been found that the system with the intake openings in the walls of the living area and the exhaust through the bathroom and kitchen is the best one for buildings having a solid type of construction. In this arrangement the fresh air from outside comes

through intake openings into the living area, and dilutes the harmful substances contained in the air in these rooms. Then the air moves on into the bathroom and kitchen area where it absorbs local pollutants and prevents them from penetrating into the living area, after which the air escapes to the outside through the exhaust ducts.

In many areas in the North, where the weather and climate conditions are very harsh, it is necessary to construct mechanical devices for drawing in fresh air from outside into living areas, and subsequently expelling it though the kitchen and bathroom area.

According to the standards, the air exchange in the kitchen must be 60 m^3/hr if there is no gas stove in it, and even if there is a two-ring stove; when a three-ring stove is used, the volume must be 75 m^3/hr while the figure is 90 m^3/hr for a four-ring stove. The air exchange from the bathroom is as follows: from the bathroom (tub only) 25 m^3/hr; from the toilet 25 m^3/hr, and from a room containing both facilities 50 m^3/hr. The same volume of air exchange must be provided for outside temperatures of 5°C with no wind. In living quarters air exchange is standardized at 3 m^3/hr per 1 m^2 of living area.

Regardless of the standardization of the parameters for air exchange in individual buildings, the question of the values for the total air exchange in an apartment is still not clear. It can be conceived as the total air exchange of the living areas and the bathroom and kitchen areas. However, it is difficult to determine it and even harder to make sure that the proper values are provided on the basis of conditions for construction of the elements of the ventilation system, expecially the ducts. Moreover, using the adopted system for ventilation, there is no need for such a high flow rate, since the air which picks up the pollutants in the living area then moves into the kitchen and bathroom area and absorbs the local pollutants there, excess moisture and heat.

Therefore, the calculated volume of air to be extracted from the apartment must be determined as follows: the required air exchange is calculated for a living area in an apartment, then the total air exchange for the bathroom and kitchen area, and from these two calculated air volumes, the largest is used for subsequent calculations.

Internal devices and systems for providing water and sewage connections in large buildings constructed in the North have no particular special conditions. Specifically, it is a very complicated matter to design pipes on the second floor for these buildings, as well as in the basement, in addition to

the outside piping. This specific problem consists primarily in the protection of the pipes against freezing of the fluids they transport and protecting the soil against wetting the soil with water overflows in order to prevent their thawing and thus avoiding deformation of the construction that could be associated with this event.

As far as the insulation for gas pipes is concerned, it is important to try to reduce the number of pipes entering the building. When there is one inlet, internal distribution of the gas can be accomplished by distributing the gas through several risers and thereby considerably reduce the amount of gas pipe that has to be laid in the soil. Entry to the building is best accomplished through the foundation or the walls of the buildings at a warm location, the kitchen for example. Installing the risers through the kitchens reduces the length of the gas pipe and reduces the number of fittings, thereby simplifying the installation of the gas pipe. Installation of gas pipes inside buildings is similar to the situation for construction under ordinary climatic conditions.

CALCULATING HEAT LOSSES

The main heat losses from buildings are determined by adding up the heat losses through the individual outside walls. Large-panel building construction often makes use of walls whose cross sections are not homogeneous for their entire area, but consist of materials and elements which have different thermotechnical properties. Heat losses through such walls must be determined taking into account the total resistance to heat transmission of the entire structure, composed of the "warm" parts and the "cold" inclusions, since resistance to heat transmission in these structures, determined by the most characteristic cross section, can give results that are higher than the real ones.

When calculating heat losses it is important to take into account correctly the infiltration of outside air through cracks in the walls, especially in buildings with a large number of stories. The Scientific Research Institute of Sanitation Technology (NIIST), with the aid of the Moscow Scientific Research Institute of Standard and Experimental Planning (MNIITEP), the Leningrad Regional Scientific Research and Planning Institute for Standard and Experimental Design of Residential and Public Buildings (LenZNIIEP) has carried out the necessary studies which allowed the compilation of a publication known as "Provisional Requirements for Calculation of Heat Losses of Residences with a Large Number of Stories," which can be used for planning with a sufficient degree of approximation.

Under these regulations, the heat losses for heating the air which enters the building through cracks around the windows and doors, calculated by conditional coefficients of heat transmission, are expressed in kcal/m^2 per hr per °C, and are related to the areas of the windows and doors. In these coefficients, heat losses resulting from heat transmission through packing stuffed into the spaces around the windows and doors, the consumption of heat required for warming the air entering through the infiltration route, and the influx of heat from the heating devices in the building are all taken into account.

DIAGRAMS AND CONSTRUCTION OF HEATING SYSTEMS AND THEIR PARTS

Modern building construction uses primarily single-pipe vertical feed systems for water supply (Fig. 10). The systems that are most often used are those with a low degree of branching, since they are most advantageous from the economic standpoint. In all cases, it is advantageous to have unilateral risers, which are placed near the slopes of the windows, with the heating devices located 350-400 mm from the slopes.

The shape and dimensions of the heating surfaces are very important, as is the nature of their location in the room. Both of these must be determined by thermotechnical and sanitary-hygienic requirements, especially in buildings in the North. As was pointed out earlier, it is preferable for inhabitants of this area to use radiant panel systems for heating, with a predominance of the radiation component in the heat transmission from their heating surfaces.

The radiant energy which is emitted from the heating surfaces is directed toward the outside walls, furniture and objects that are in the room, and is partially absorbed by them, and partially reflected, creating a slightly reduced secondary radiation which in turn is absorbed by other outside walls and objects.

Human beings who are in rooms with heaters of this kind are subjected to the crosswise effect of direct and reflected radiation. The absorbed and reflected radiant energy is thereby converted into thermal energy and increases the temperature of the objects and the walls. This fact is a favorable one for those living inside since it enables them not to feel any temperature drops in the outside air. Therefore rooms which are heated by such devices can be ventilated

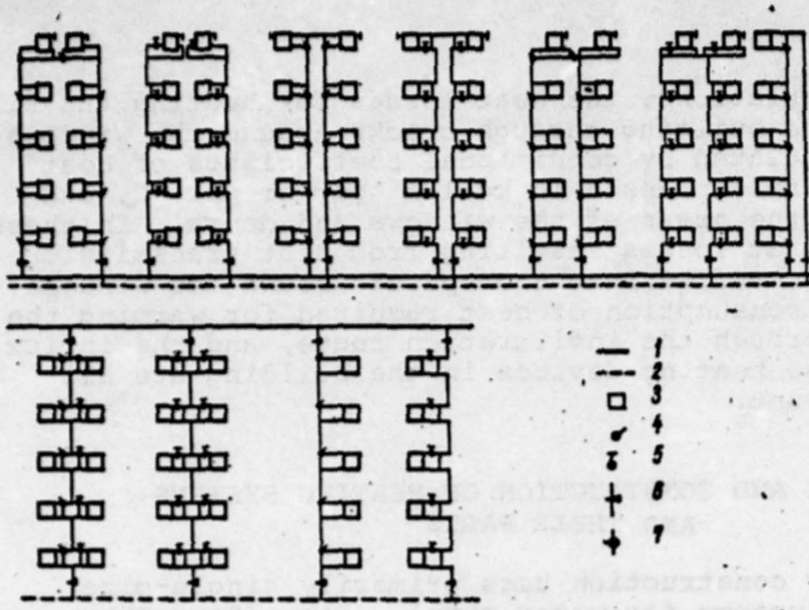

Fig. 10. Diagrams of single-pipe vertical feed systems for water supply for heating.
1 - hot water pipe; 2 - return pipe; 3 - heating device; 4 - three-way valve; 5 - double-control valve; 6 - drain valve; 7 - air valve

more slowly during the cold time of year than under the influence of an ordinary radiator (convective) heating system, thus allowing an improvement of the air environment in the living areas and have a positive influence upon improving the feelings of well-being and increasing working capacity. In addition, convective air flows in these rooms are weaker than in a radiator heating system, thus allowing dust to settle at lower levels in the room.

The increased radiation component for heat emission is also typical of flat smooth heating surfaces. They can be made of metal or concrete. The latter are preferable, since the temperature of their surfaces is lower than that of metal ones.

Concrete heating surfaces are made either in the form of individual panels (Fig. 11) with integral heating elements made of smooth metal tubing of different shapes, or by incorporating pipes (Fig. 12) in concrete walls or horizontal surfaces like floors and ceilings.

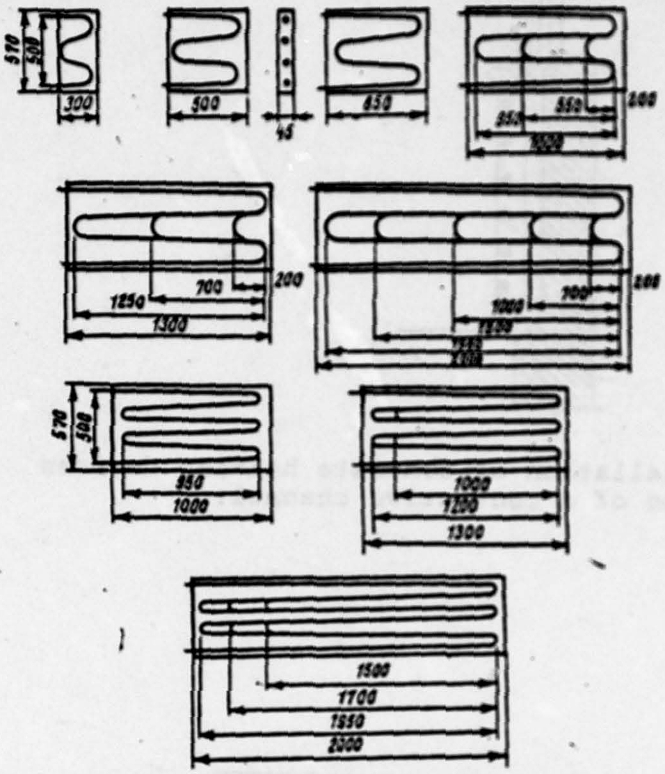

Fig. 11. Concrete heating devices.

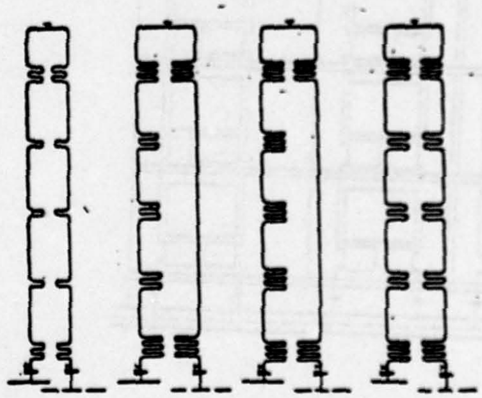

Fig. 12. Diagram of installation of heating elements in a wall.

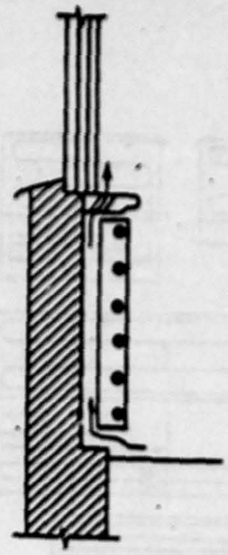

Fig. 13. Installation of concrete heating devices with formation of a convective channel.

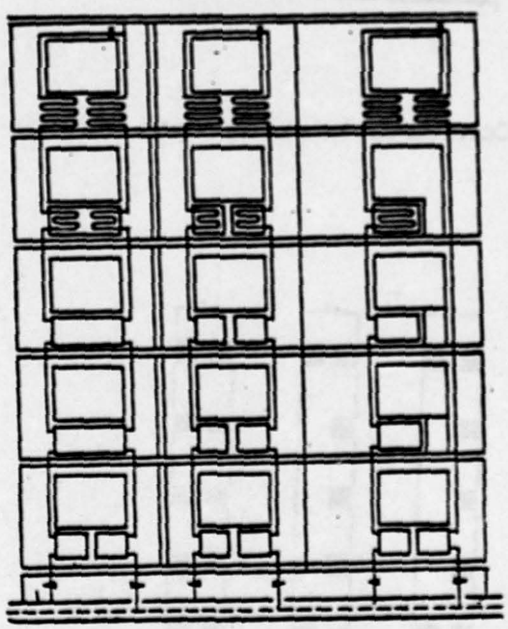

Fig. 14. Installation of one and two concrete devices in niches and installation of coils (two-wire system).

Concrete heating surfaces in the form of individual panels, the so-called concrete heating devices, are placed in niches or cutouts in the structure of the building and tightly up against them, with unilateral heat emission or close to the surfaces of the buildings, forming convective ducts for bilateral heat emission (Fig. 13).

When concrete heating devices are built, it is very important to choose their dimensions correctly; to a large degree, they are determined by structural features and the dimensions of the surrounding structure. When devices are installed beneath windows, their length must correspond to the length of the niches.

One or two devices can be installed in niches or a coil can be installed in the wall (Fig. 14). This makes it possible to reduce the dimensions, which can be considerable in the case of buildings made of large panels. In this case, a water distribution system is used in which the average temperatures in each pair of heating devices are the same and are equal to the average temperature of the water in the riser. This arrangement of risers is called the two-wire system. Since the heating loads on rooms that are located one above the other are similar in magnitude, pairs of devices on the middle floors of the building will have the same heating surface. Devices mounted in pairs can be mounted in the corner apartments, in apartments with two windows, in two adjacent apartments with one window each, when elongated wall panels consisting of two windows are used.

The height of the concrete heating device is chosen as a function of the height of the niche. Between the floor and the lower edge of the device, it is necessary to leave an intake convection slot 5-6 cm high. The wall beneath the window must be in contact with the upper edge of the device, while the exhaust slot for the convective panel between the rear surface of the device and the surface of the niche must be installed in the wall beneath the window. In this case, the flow of hot air is directed along the window and heats the glass, which is very important to cut down on negative radiation.

To manufacture tubular heating elements for heating panels, it is advantageous to use pipes with small cross sections, with thin walls, which have a low mass: water and gas pipes 15 mm in diameter or thin-walled electrowelded pipes 18 x 1.5 mm. When using pipes of this kind, the thickness of the device should be 45-50 mm. The thickness of the protective layer of concrete from the surface of the pipe to the surface of the device should be at least 8 and no more than 10 mm, and the distance from the axes of the pipes to

sides of the devices should be at least 35 mm.

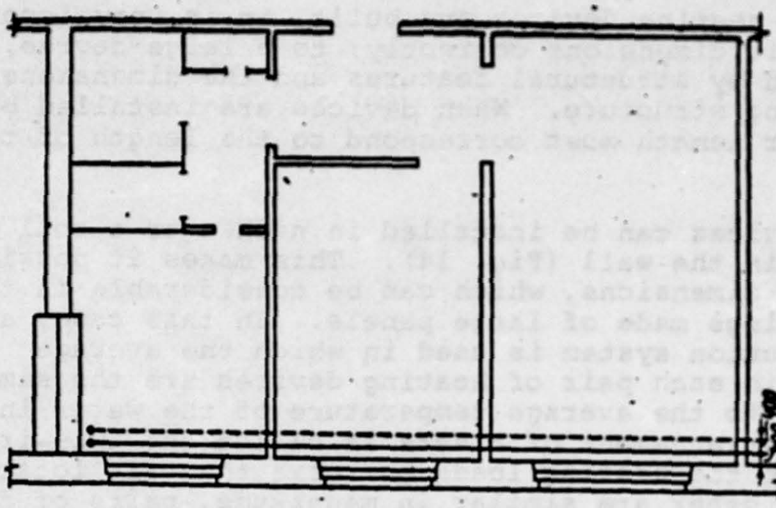

Fig. 15. Installation of pipes for a contoured ceiling-floor water heating system.

The coiled form of the heating elements ensures that there is a minimum number of welded connections, a high rate of travel for the heat-carrying substance, uniformity of heating and the possibility of flushing out the pipes.

Among the most highly prefabricated heating systems undoubtedly are the floor and ceiling radiant systems. The heating elements in these systems are smooth pipes which are laid in the concrete, not over the entire surface of the panel but only along the perimeter or along the edges of the building, along the outside walls (Fig. 15). The heat emission comes primarily through radiant energy from the surface of the ceiling. The total radiational heat flux then falls within the conditions specified by hygienic standards.

Calculations show that in the case of residences in which the rooms are 2.5-2.7 m high, such systems can be used with a heat-carrying substance of usual parameters, 95-70°C, which is also confirmed by hygienic studies under actual operating conditions. When concrete heating surfaces are installed

vertically, in the walls or on the walls, a heat-carrying substance with 115-70°C parameters can be used.

INSTALLATION OF VENTILATION INTAKE CHAMBERS

Construction of intake ventilation systems for residences is very difficult due to the large size of the equipment that is used, the large amount of noise which is produced and the complexity of operation.

It is not allowed to install ventilation chambers inside a residence on the same floor where apartments are located, but they must be installed only on floors where auxiliary services are located. In apartment houses, these rooms can be installed inside the building. However, in both cases sound insulation of the fan equipment must be provided by using a vibration-insulating type of foundation, double coverings and walls in the chambers, and providing noise-absorbing material in the air ducts.

In those cases when all the floors of an apartment house are occupied by apartments, ventilation chambers must be built outside the building proper, inside a separate service building, which communicates with the apartment house by enclosed heated passageways or tunnels (Fig. 16). Air ducts must also pass through these passageways, allowing engineering communications with the building and bringing out the sewer lines to the nearest sewer.

In these service buildings, it is recommended that the control systems for the heating system be installed, as well as the heat-generating devices, and the water meters and other monitoring devices for checking on the operation of the equipment.

Operational and calculated expenses for locating equipment in a service building are less than when they have to be included inside the building itself. When equipment is installed in a residence, the living area is reduced, thus increasing its net cost. In addition, the use of such installations makes it possible to do the following:

Completely the area served by the equipment from the noise that is produced by the fans;

Using standard installations for the equipment;

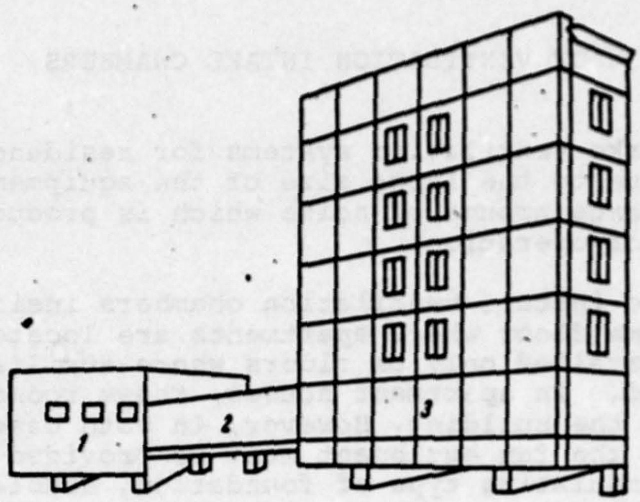

Fig. 16. Location of a service building.
1 - service building; 2 - enclosed tunnel connecting the buildings; 3 - apartment house.

When using one building to serve as several apartment houses, the fan installations can be made more powerful and their number reduced, thus simplifying servicing, and cutting down the possibility that the intakes and exhausts will freeze up.

At the same time, installing separate auxiliary buildings in the area as well as their connecting tunnels complicates planning; in some cases it is even impossible.

The advisability of locating engineering equipment directly in the building or in separate auxiliary buildings must be settled by the architectural and planning department for the area. To some extent the buildings themselves determine the decision. When using the first floors of residences for auxiliary installations, there is no need to install the equipment in separate buildings. Fig. 17 shows equipment installed in a separate building.

It is possible to install fan chambers beneath staircases and attics of rooms in special types of design, and the intake chambers can be installed beneath the staircases of residences and public buildings if the necessary measures are taken to protect against noise and to absorb the sound.

Under northern conditions, one very important factor as far as equipping centralized ventilation systems is concerned is automation aimed at ensuring continuous operation of the systems, achieving the necessary parameters for processing the air and preventing freezing of the parts of the equipment.

To protect the heat-carrying pipes against freezing, it is possible to recirculate some of the air, heating it and mixing it with the outside air before the latter enters the heating system. Recirculation can be accomplished by increasing the capacity of the intake fan by approximately 1.5 times or by installing a special fan. The recirculated air can be heated to 60°C and at this temperature one can produce an air temperature which is at least -20°C when it hits the heating system.

When the air temperature in the mixing chamber drops below the set limit, it must be possible to switch the intake valve and cut down the intake of air from outside. To maintain the desired temperature in the humidifying chamber and in the intake system it is recommended that automatic regulation be provided for the flow of heat-carrying substance in the heating system for both primary and secondary heating, operating with air at a positive temperature.

Provision must be made to protect the electric motors driving the fans, the sprinkling chamber pump and the electrical wiring to the heated air intake valve.

A diagram showing these antifreezing measures for heaters is shown in Fig. 18. The heaters are divided into groups: those for preliminary heating of the air to 60°C; the preliminary heating to achieve an air temperature coming out of the mixing chamber of 10°C; heaters for reheating the air and bringing it up to 29°C before it is adiabatically humidified and finally a second heating system which heats the air downstream from the humidification chamber to the air temperature of the apartments.

In order to heat the air, there are single-duct and multiple-duct heaters which are produced by industry through which the heat-carrying substance as a rule flows at rates up to 0.8-1.2 m/sec.

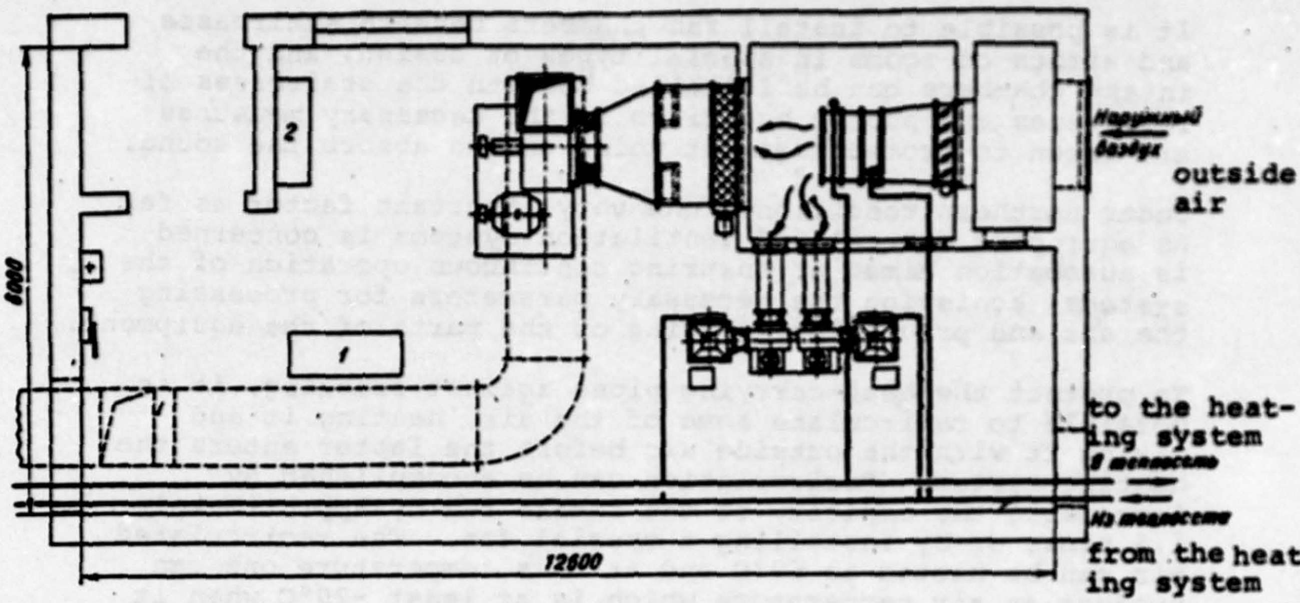

Fig. 17. Diagram of the installation of equipment in a separate auxiliary building.
1 - control and measurement devices; 2 - electrical control panel.

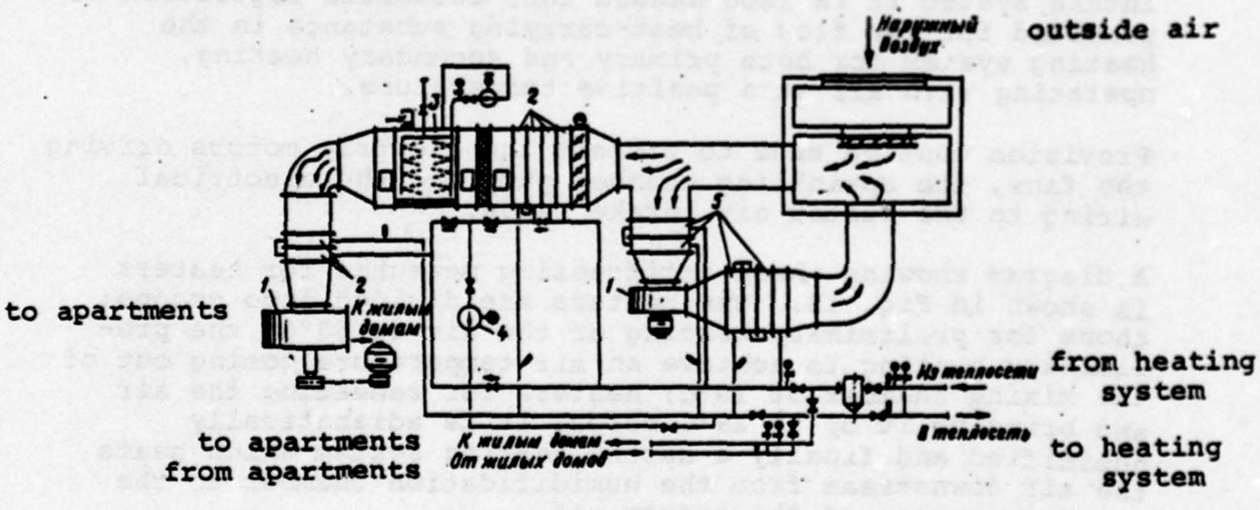

Fig. 18. Diagram of the installation of equipment taking into account measures to prevent freezing of the heating system.
1 - centrifugal fans; 2 - air heaters; 3 - sprinkling chamber; 4 - centrifugal pump; 5 - heaters

Studies have shown that with normal operation of heaters which provide an average heating medium speed of at least 0.15 m/sec under favorable conditions, the danger of freezing of the heating medium in the heater is eliminated.

In single-duct heaters, in which the flow of heating medium is rectilinear, it will not freeze at low temperatures and low speeds down to 0.006 m/sec. In the event of passage of cold air through a closed valve in the air intake system, the bypass for the control valve for the heating medium must be provided with a bypass line (made of tubing 10 mm in diameter) for constant feed of heating medium to the heaters.

At the present time, the "Volna" heater made of sheet metal is produced, and is highly resistant to freezing. It has a flattened oval pipe which changes its cross section when it freezes, becoming more circular in shape, thus making it possible to eliminate considerable stresses on the walls of the pipe.

HUMIDIFICATION OF THE AIR

In northern regions, the moisture content of the air is low during the cold season of the year, and this is difficult for people who live there. It makes it necessary to humidify the air which is pumped into the building. Humidifying this air by using irrigation chambers poses certain difficulties, due to the cumbersome size of the equipment, the complexity of servicing it, and the deficiency of the conditioning systems of which they are a part.

These facts have necessitated a search for other solutions to the air conditioning situation. One of these is to use the foam-evaporating humidifier (FEH) designed by LenZNIIEP* (Fig. 19). It can be used not only to humidify the air but also for heating it.

The FEH works as follows. The air is heated and humidified by cooling it with water in heat exchanger pipes and evaporating the water into a layer of water-air emulsion, which flows over the heat exchanger. The air-water emulsion is produced by the energy of the air flow which comes in through the air intake pipe and strikes the surface of the water,

* Designed by E. A. Astapov, A. L. Bek-Kergun, Yu. V. Konovalov, and A. F. Spiridonov.

which has been placed in the lower part of the housing of the apparatus.

When using the FEH to condition the air, the following combination solutions for the intake system are possible.

1. Successive processing of the air. In this case the outside air is sucked in by a fan and compressed into the foam-evaporating apparatus where it comes in contact with hot water, is heated, is simultaneously humidified to $\varphi = 100\%$. From this device the air goes into the heat exchanger for reheating, where it is heated to the desired temperature and then goes into the apartments.

2. Parallel processing of the air in heaters and the foam-evaporator humidifier. Three methods for processing the air are available:

a) A portion of the outside air sucked in by the fan passes through the heaters, where it is heated to the desired temperature, while another part of it passes through the humidifier. Later both of the air components are mixed and then pumped into the apartments by a fan;

b) All of the outside air passes through the heater, where it is heated to the desired temperature. Then some of the heated air goes into the foam-evaporating system where the air is humidified and is then mixed with the main body of the air, then pumped into the apartments by a fan;

c) The air is fed into the ventilating system by two fans, which supply air through the heater and a fan from the foam-evaporating humidifier. Some of the air which is heated in the heater is mixed with outside air to prevent the heaters from freezing. Another part of the heated air is mixed with the moist air coming out of the foam-evaporator humidifier. After the air has been mixed, it is pumped into the ventilation system.

The technical and economic analyses have shown that using the FEH instead of a sprinkling chamber reduces the operating expenses by a factor of 2.4 and the total expenses by 12%; electrical energy consumption is reduced 1.3 times.

The air can also be humidified by using a standard sprinkling chamber of the type designed by the Santekhproyekt Institute, which has smaller dimensions than the sprinkling chambers of air conditioning machinery. It is 1.25 m long, and varies in width from 1.5 to 4.3 m depending on its capacity. The nozzles

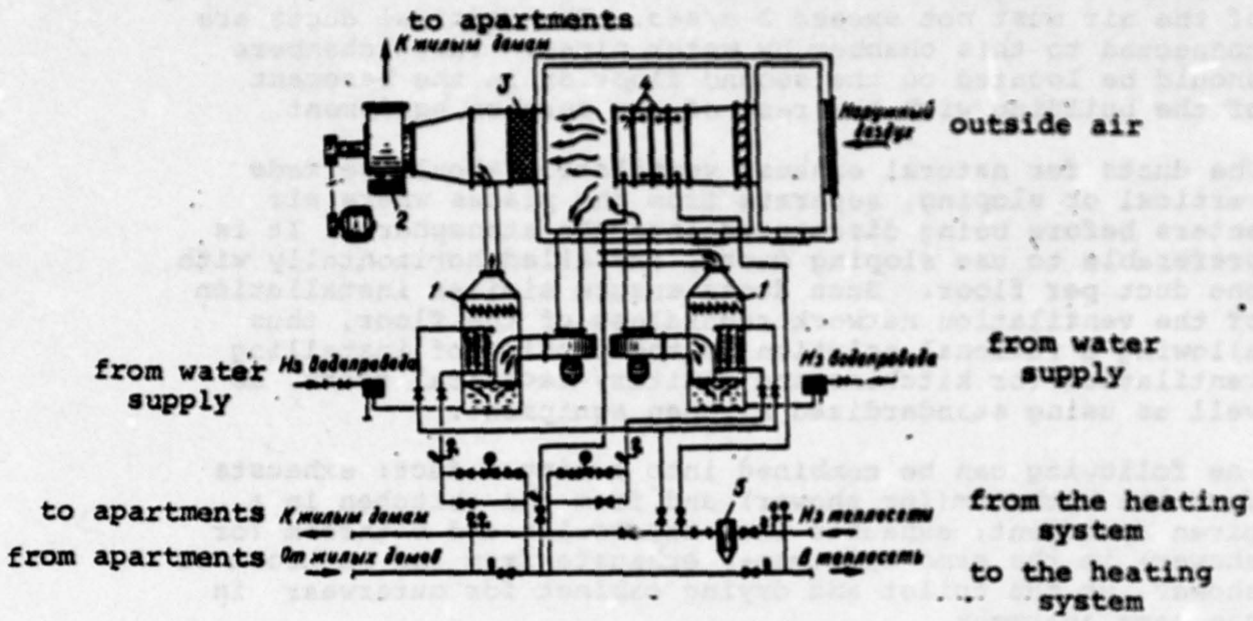

Fig. 19. Diagram showing locations of equipment using the foam-evaporator humidifier (FEH). 1 - FEH; 2 - centrifugal fan; 3 - filter; 4 - heaters; 5 - sludge trap.

installed in the chamber deliver a fine spray and allow the humidification process to be shut off at any point, allowing the reheated air to be excluded from the processing system.

AIR INTAKE AND EXHAUST. DESIGN OF DUCTS

When designing ventilation equipment it is very important to take into account the necessary aerodynamic and structural conditions for correct guidance of the intake and exhaust air. It is important to keep in mind that in large-panel and brick construction considerable use is made at the present time of concrete or other types of blocks to build ventilation ducts. The latter have dimensions which are determined not by aerodynamic conditions but by structural factors, thus making it impossible to regulate the air flow. In this case the regulation of the amount of air to be exhausted is possible only if controlled grids are used.

To ensure uniform exhaust of the intake air through the ducts, it is recommended that a device be provided between the intake chamber and the ducts for the static pressure chamber, a large cross section air duct in which the velocity of the air must not exceed 2 m/sec. The vertical ducts are connected to this chamber by water pipes. These chambers should be located on the second floor or in the basement of the building with the rest of the service equipment.

The ducts for natural exhaust ventilation should be made vertical or sloping, separate from the places where air enters before being discharged into the atmosphere. It is preferable to use sloping ducts, installed horizontally with one duct per floor. Such ducts ensure similar installation of the ventilation network regardless of the floor, thus allowing a rational solution to the problem of installing ventilation for kitchens and sanitary-technical rooms, as well as using standardized kitchen equipment.

The following can be combined into a single duct: exhausts from the bathroom((or shower) and from the kitchen in a given apartment; exhausts from the toilet and bathroom (or shower) in the same apartment; exhausts from the bathroom or shower, or the toilet and drying cabinet for outerwear in the same aparment.

Exhaust ducts can be circular, oval or square in cross section. The diameter of the large channels should not be less than 127 mm. Oval channels must have a cross sectional area of at least 136 cm^2 with a ratio between the axes of the oval of no more 2:1. Square ducts should not measure less than 120 x 120 mm, with the radius of curvature at the corners not being less than 50 mm. When these cross sections are used for the ducts, their number in the apartments must be determined on the basis of Table 12.

Table 12

Number of exhaust ducts in apartments as a function of the floor and living space of the apartment

No. of the floor in the building, from the top	Living area of apartment, m^2			
	up to 30		above 30	
	in the kitchen	in the bathroom	in the kitchen	in the bathroom
1	2	2	2	2
2	2	1	2	1
3	1	1	2	1
4	1	1	2	1
5	1	1	1	1

Due to the construction problems associated with installing a large number of separate exhaust ducts in residences with more than five stories, it is allowed to install in such buildings a system of combined separate exhaust vertical ducts, provided the following conditions are met:

The ducts from each four-six floors must be combined spearately;

The cross-sectional area of the collecting ducts for collecting shafts must be no less than the total area of the cross sections of the connecting ducts;

The distance of the collecting ducts from the points at which the vertical exhaust ducts connect to the exhaust shafts must not exceed 5 m;

The number of turns which the air must make in the horizontal collecting duct must be as small as possible and must not exceed three;

The ducts to the upper floors must be closest to the exhaust duct along the path traveled by the air.

It is also permissible to combine the sloping exhaust ducts into a single vertical duct, but the ducts from the top two floors must be left separate.

The ventilation systems for apartments must not be combined with the ventilation systems from kindergartens, nurseries, shops and other facilities sharing the building.

In order to increase the air exchange when open gas flames are present and subsequently ventilate the rooms in the apartments, when there is no corridor or vent between the kitchen and the living room, electric exhaust fans should be installed. However, it should be kept in mind that the installation of fans is only permissible for separate ducts, and when there is no gas water heater in the apartment which discharges the combustion products into the chimney.

In apartments which are located above the neutral zone, equipped with exhaust fans or hoods above the gas burners, special supply ducts must be provided mounted above the heating devices and having reliable shutters to control the flow of air inward.

Rooms containing bathroom fixtures and kitchens, fitted with gas water heaters, must be provided with an influx of fresh air at the floor through a grating with a cross-sectional area for the openings of no less than $0.02m^2$ through a gap between

the door and floor of the same room. The doors of the bathrooms must open outward. Air vents or transoms must be provided for periodic ventilation of the rooms and kitchens.

It should be kept in mind that the air exchange described above is inadequate for localizing contamination that saturates the air of the kitchen, when there are gas burners in it with open gas flames. In this case the air circulation in the kitchens must be increased to 200-220 m^3/hr. This level of air exchange can be provided either by intake fans or a mechanical exhaust.

Therefore, in those regions of the North where the standards require that residences that are piped for gas must be equipped with intake ventilation, the necessary amount of air must be provided to the different apartments. However, when the intake ventilation is not installed and the gas burners are installed, exhaust ducts for the kitchens on all floors should be installed so that they have individual exhaust fans in each apartment. In this case all the ducts must be separate.

Buildings with more than nine stories must not be piped for gas. Electric burners must be installed for cooking food, and hot water must be provided by centralized systems.

In northern regions and especially those with a harsh climate, where it is difficult to ventilate buildings, the use of gas in residences with any number of stories must be ruled out, and a changeover to electrification for cooking food and centralized hot water must be effected.

The designs described above for apartment houses with separate ventilation ducts also lend themselves to systems for intake ventilation. Separate ducts are preferable from the construction standpoint as far as installing intake and exhaust ventilation systems is concerned because they make it possible to reduce the number of ducts considerably, by using a single duct both for intake and exhaust. The incoming air is fed through the lower part of the duct from the bottom to the top up to an exhaust opening, above which a dead end is provided in the duct, while the intake grate is for the exhuast air is installed above it, and the upper part of the duct operates as an exhaust duct by natural action.

As a rule, these units are installed in the vicinity of the bathroom and kitchen area, and the incoming air must enter the living room, so that distributing air ducts must be installed. As shown in Fig. 20, they should be installed in a definite pattern. Then the incoming air, emerging from the room and entering the bathroom and kitchen area, is removed through the exhaust ducts. The basement of the building must have its own exhaust duct for each section of the building.

For ventilation during winter and intermediate seasons of the year, the staircases should be equipped with air vents for special exhaust devices located in the upper part.

To intall vertical ventilation ducts, spaces must be provided in the inside walls of buildings or special duct assemblies and separate auxiliary ducts must be installed. The latter must be mounted on the inside walls and partitions.

The material used for duct assemblies can be concrete, slag concrete, or keramzit concrete. The thickness of the partitions between the ducts as well as the walls of the ducts themselves must be at least 3 cm.

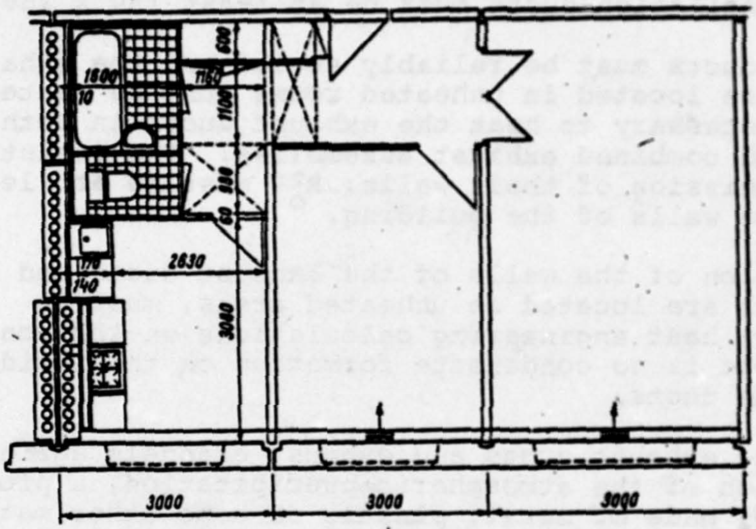

Fig. 20. Diagram of the layout of horizontal feed ducts in the apartment.

The ends of the assemblies must be provided with devices to prevent the solution from running into the ducts when the ducts are installed, for example, elastic partitions made of sheet "orgalit" or asbestos, soaked in a cement or plaster solution. When the walls of the ducts are less than 5 cm thick, it is recommended that assembly openings be provided in duct structures , making it possible during assembly to cover up and block the horizontal seams by hand from the inside of the ducts.

The material for the feed and suspended ducts must be selected with an eye toward the purpose of these ducts and their location; the correspondence of the ducts to architectural and structural regulations; fire safety; strength;

economic parameters; possibility of mass production.

The feed and suspended ducts can be constructed in locations with normal humidity conditions from asbestos cement, plastic, cardboard tubing, saturated with fire-and moisture-resistant compounds, plaster-hair or plaster-slag panels (35 mm thick), gypsum dry plaster; in locations with high humidity (kitchens, bathrooms) from asbestos cement, plastic, slag-concrete, concrete or gypsum-hair panels (40 mm thick).

Horizontal ventilating ducts, connecting the ventilated rooms with the collecting ducts, can be designed to hang from the ceiling or the spaces between the concrete and the flooring can be used as ducts. The dimensions of the horizontal ventilation ducts must be at least 150 x 150 mm.

All of these ducts must be reliably sealed and the exhaust ducts which are located in unheated rooms must be heated. Thus, it is necessary to heat the exhaust ducts in both individual and combined exhaust assemblies. The resistance to heat transmission of their walls, R^{tr} must be at least $0.85R_o^{tr}$ of the walls of the building.

The construction of the walls of the exhaust ducts and channels which are located in unheated areas, must be checked using heat engineering calculations on the condition that there is no condensate formation on the inside surface of the ducts.

To protect the exhaust ducts and exhaust channels against the penetration of the atmospheric precipitation, a protective canopy made of metal, plastic or some other material must be provided. The vertical distance from the end of the exhaust duct or channel to the bottom of the protective shield must be equal to the equivalent diameter of the cross section of the shaft or each of the exhaust ducts. The width of the hood must be equal to twice the width of the exhaust ducts covered by the hood. The height to which the air is discharged from the middle of the windows of the top floor must be at least 2.7 m.

HEATING AND VENTILATION OF MOBILE HOMES

Mobile homes are small houses that can be assembled and taken apart and moved around, made of light construction, which can be moved around many times by different types of transportation. The outside structures of mobile homes are made of highly efficient construction materials. Thus, the heat insulation consists of various cellular plastics, which possess high heat-insulating properties, and the siding is made of materials which are practically impermeable to water and vapor, as well as fiberglass, sheet aluminum, and high-strength waterproof cardboard.

The high level of hermetic sealing of houses which can be put together, taken apart and moved around, their insignificant thermal resistance, small volume of living space, lack of fuel and electricity in the areas where they are used, as well as the harsh climatic conditions in the North, which are characterized by low temperatures combined with strong winds, all of these require a new approach to means of ensuring a comfortable microclimate in buildings.

In developing projects for mobile homes, it is impossible to use not only existing heating and ventilation systems, but the principles that are used in designing and constructing them, including the standards for calculations. It is particularly important to emphasize the fact that the choice of the heating and ventilation system is always connected with the requirements which are imposed on the microclimate of the residence who will differ, depending on whether they are the native population or people who have come from moderate latitudes of our country to work in the North.

The construction of stoves for central heating, even in settlements which number several tens of houses is not economically feasible. It is a very difficult thing to lay outside pipes in areas where there is permafrost,and it entails considerable financial investment; the operation of central heating systems would cost many times the price of other heating systems. Reliability of this kind of a heating system is low because of the considerable danger of the pipes breaking if they are of small diameters when low temperatures occur in the outside air.

In the first experimental houses which were built by the Lengiprospetsgaz Institute, a type of hot water heat was used with the "VNIISTO-Mch" water-heating boilers, located in each house. The output of these boilers was 14,000 kcal/hr.

They burn coal or wood.

Fig. 21 shows a typical mobile house, intended for four people. It measures 3 x 9 m, and is 2.5 m high inside. The house has two rooms, each equipped with special furniture. In the auxiliary room which is located between the two living areas, there is a washstand and a drying cabinet for clothing and footwear. According to the standard requirements for cold regions, two stoves are mounted in the house, one of which is used as a place for preparing food.

The outside structure of the hous consists of panels three layers thick, made of an outside covering (extra hard wood and fiber material 4 mm thick), insulation (PCV foam plastic, 130 mm thick in the walls and roof and 170 mm thick on the floor) and an inside covering (wood fiber paneling, 6 mm thick). The roof is also covered by galvanized iron 0.5 mm thick. The house is mounted on a metal frame, to which an undercarriage can be attached, either skiis or skids.

There is a two-pipe water supply system in the house, with a pump. The heat is supplied by water at a temperature of 90 - 70°C. The hot water pipe is laid beneath the ceiling, and the return pipe is beneath the floor. The heaters are stamped steel radiators (model MZ-350). When there is no electricity, the system can be driven by natural circulation.

The house is ventilated by an intake-exhaust system. Air is drawn into the living rooms by means of a mechanical device, while the exhaust is natural, using a vent with deflectors. The efficiency of the fan is chosen to take into account an adequate supply of air, which is supposed to be 30 m^3/hr per person and 60 m^3/hr for the heater.

An interesting variety of hot-water heat, unlike the individual water-heating boiler, has been proposed by the Promstroymaterialy Trust (Moscow) in the experimental model of a all-metal combined living unit (TsUB). The design of the unit (Fig. 22) is an all-metal tube, 3.2 m in diameter and 9 m long, with reinforcing rings made of angle iron. PCV foam plastic is the insulation, 0.1 m thick. The inside lining is made of 4-mm paneling, covered with a washable finish. The house is equipped with special furniture and the necessary engineering and housekeeping supplies. The unit is mounted on metal runners to be pulled by a tractor, but can also be transported by helicopter.

The heating convectors are of the 20 kp plenum type, located beneath the floor of the building. The cold air enters the space beneath the floor through a grill at one end of the unit, is heated, and passes through supply ducts in the floor into the rooms at a temperature of 20 - 25°. The warm floor also radiates heat to the inside surfaces of the walls and to objects which are in the room.

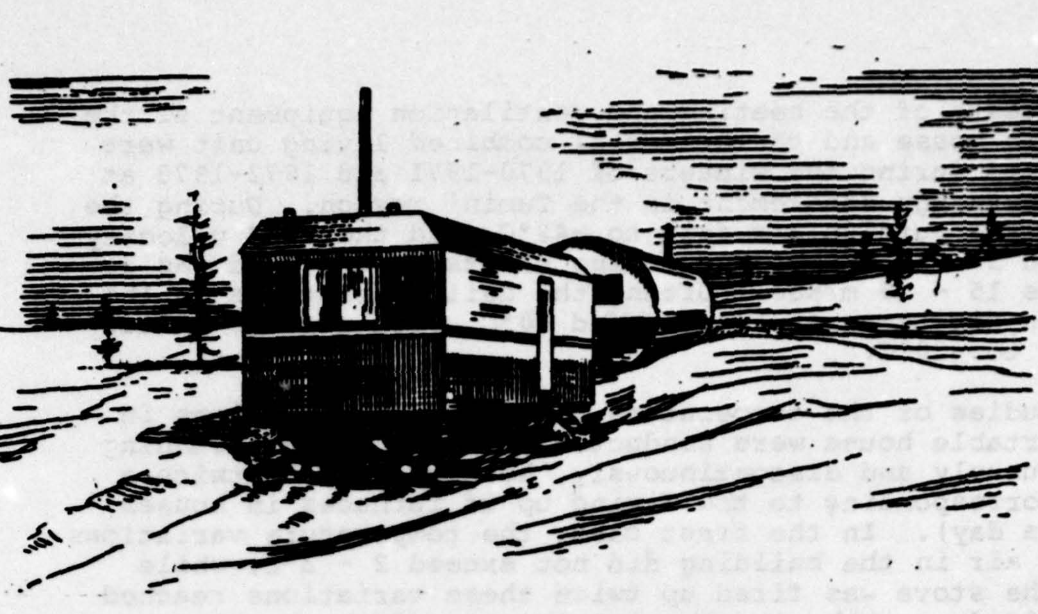

Fig. 21. Moveable house - general purpose.

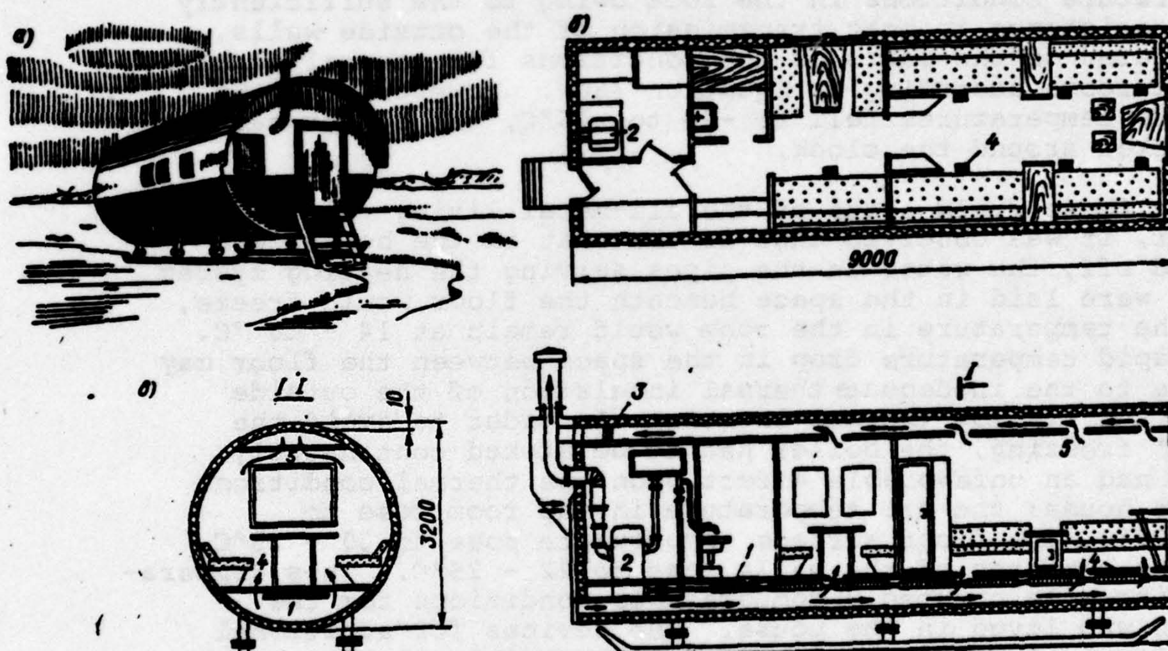

Fig. 22. All-metal combined living unit (TsUB).
a - outside;view; b - top view; c - cross section and lengthwise section; 1 - ducts; 2 - water-heating boiler; 3 - fan; 4 - intake grids in the floor structure; 5 - exhaust openings in the ceiling structure.

Field tests of the heating and ventilation equipment of the portable house and the all-metal combined living unit were performed during the winters of 1970-1971 and 1972-1973 at the Labytnangy settlement in the Tumin' region. During the tests, the outside air fell to -48°C, and the wind velocity reached 5 - 10 m/sec, and during blizzards the wind was as high as 15 - 20 m/sec. Often, the daily variations in the outside air temperature exceeded 30°C, with average values of -25 to -30°C.

The studies of the temperature and humidity conditions in the portable house were conducted with the boilers running continuously and discontinuously, heating them up twice a day (corresponding to the firing up of furnaces in houses twice a day). In the first case, the temperature variations of the air in the building did not exceed 2 - 3°C, while when the stove was fired up twice these variations reached 8 - 10°C due to the low thermal inertia of the heating system and the house as a whole. A sharp temperature drop in the outside air did not have a significant influence on the temperature conditions in the room owing to the sufficiently high resistance to heat transmission of the outside walls, calculated on the basis of the conditions for thermal stability of the rooms according to Equation (60). However when the outside temperatures fell to -40 to -45°C, the boiler had to be stoked around the clock.

During these field tests of the all-metal living unit during winter, it was observed that if the heat in the boiler was turned off, the water in the pipes serving the heating system which were laid in the space beneath the floor would freeze, and the temperature in the room would remain at 14 - 16 °C. The rapid temperature drop in the space between the floor may be due to the inadequate thermal insulation of the outside walls and its low thermal inertia. In order to avoid the pipes' freezing, the boiler had to be stoked continuously, which had an unfavorable effect upon the thermal conditions in the house: the air temperature in the room rose to 27 - 29°C, the floor surface temperature rose to 30 - 33°C, and the surfaces of the walls rose to 22 - 25°C. This temperature increase created uncomforatable conditions for the people who lived in the house. The devices for additional heat insulation on the pipes made it possible to keep them from freezing but still when the boiler was stoked twice a day the temperature variations in the rooms reached intolerable levels.

However, the principal shortcoming of these systems of heating using water-heating boilers in portable houses are not the

difficulties in maintaining the necessary conditions in the living quarters but rather the fact that they are not easily portable. In the majority of portable houses, the heating and ventilation equipment was completely or partially damaged, resulting in considerable damage to the inside surfaces and structure of the buildings.

At the present time, a decision has been made to replace the water heat in these buildings by electrical heat, with automatic regulation of temperature. For a service building and one of the residential blocks of houses made of plastic (See Fig. 4) the LenZNIIEP (KF. Velikiy) developed a design of electric heat based on low temperature panels which have a strongly developed heating surface. The heating elements, made of three sheets of material stuck together with an inside winding of constantan wire (0.3 mm in diameter) were mounted beneath the inside paneling of the walls in the air space that communicated with the outside and inside air of the building. The outside air, entering through openings into the air duct, was heated by the electric panels to temperatures of 20-22 °C and then entered the room. Circulation was accomplished by using fans, mounted in the residential area of the building. The inside surfaces of the walls, heated to 40 - 45°C (at the points where the electric panels were installed) served as the source of radiant heat.

The dimensions of the standard panel were 0.75 x 0.5 m. The power draw of an individual heating element was 450 watts, corresponding to radiation of 280 kcal/hr/m^2. With such a thermal density in the panel, a maximum temperature of 45°C could be attained, which is completely unsafe from the fire standpoint. The number of electric panels was determined by the heat consumption required for maintaining the necessary temperatures in the building. Since the heating panels also serve to heat the intake of outside air, their surfaces were increased 40%. The degree of heating of the intake air was established automatically, since the colder the incoming air was, the hotter the heating panel would have to be. Regulation of the heat was accomplished automatically using TRG-1 thermostats mounted in each room. By using these devices, the required temperature could be set in each room (18 - 22°C), and then be maintained automatically, regardless of the outside temperature.

Field tests of the service building and one living section of a plastic house were preformed at the Palatka settlement in the Magadan region during the winter of 1970-1971; they demonstrated the high performance capability of the heating and ventilation systems that had been installed. The intake and exhaust ventilation system ensured that the air in the building was changed five times every hour without causing any significant temperature changes in the air in the room

from the said values. The greatest variations that were observed during the tests did not exceed 1 - 1.5°C. The existence of radiant heat in the room made it possible to drop the temperature to 18 - 19°C. Uniform distribution of heating panels over all of the walls produced very good temperature comfort conditions in the residential areas, since the human body received radiation uniformly from all sides. The comparatively low temperature of the heating surfaces (30 - 45°C) did not create considerable contrast with the cold surfaces of the outside walls (16 - 18°C).

The residential area II of the plastic house (See Fig. 4), which was tested at Leningrad, was heated by electric heated radiators mounted in the living area, and the air was circulated by an intake-exhuast ventilation system with preliminary heating of the outside air. When using radiator-type heat with individual control of each unit, it was very difficult to achieve uniform distribution of the temperature in the room. Although the temperature variations of the air did not exceed 1 - 2°C, its variations within the height of the room reached 4 - 5 °C, with a sharp drop at the surface of the floor. The concentrated feed of ventilating air increased the air mobility in the room to 0.20 - 0.25 m/sec. The location of the electric radiators largely depended upon the interior and the small area within the living room was reduced even further. However, despite all of these shortcomings, the electric heating system was simple to use and provided an interior microclimate which satisfied all the requirements that were imposed on residential buildings.

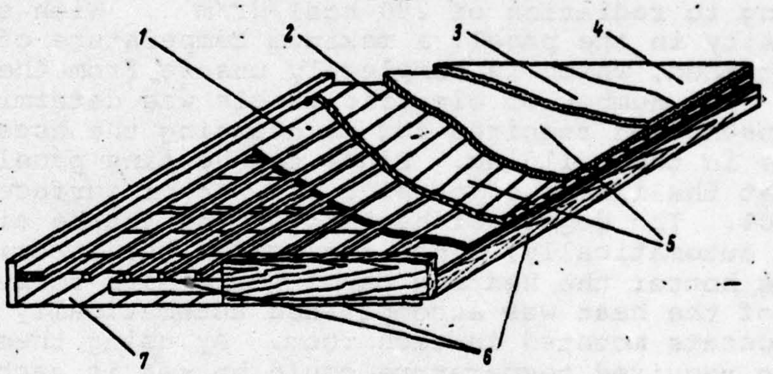

Fig. 23. Design of floor, heated by electric cable.
1 - packaged microporous rubber; 2 - electric cable; 3 - wood fiber panel; 4 - linoleum; 5 - asbestos-cardboard; 6 - wooden stringers to support the floor; 7 - steel screen.

In a building developed by the heat engineering laboratory of the frost station of Lenmorniiproyekt, built at the

Amderma settlement on the coast of the Caspian Sea, in addition to a radiator-type electric heater, a warm floor was provided in two rooms. Beneath the surface (Fig. 23), between layers of asbestos-cardboard, an electric cable was laid provided with a heat-conducting center and a PCV insulation. For improved radiation and distribution, the surfaces of the wires, once installed, were covered with a thin layer of dry sand. Low voltage electric current was fed through the cable (25-37°C).

Air circulation was provided by an intake-exhaust ventilation system. The cold outside air, entering through openings located beneath the windows of the house (Fig. 24) into a space that was formed by the radiator, screen and side walls, was heated and then fed into the room at 15-20°C. The exhaust fan was located in the entry and made it possible to regulate the air exchange in the building.

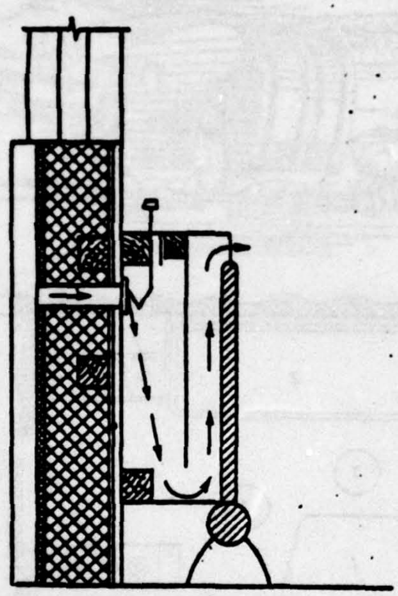

Fig. 24. Diagram of device for intake ventilation in the house (Amderma settlement).

The use of radiator-type heat with the heating system described above along with a heated floor made it possible to achieve uniform temperature conditions throughout the building. Automatic temperature regulation made it possible to use electrical energy to heat the house only within the required limits without overheating it. When the electric heat to the floor was shut off, the result was not only a considerable drop in the temperature of its surface (to 10°C) but also a sharp temperature differential measured vertically, disrupting the temperature comfort conditions in the room.

At the present time, the plastics department of LenZNIIEP has developed and built several varieties of moveable houses for

sovkhozes which are in charge of reindeer herds. The little houses are made of efficient lightweight materials: they are supported on a framework made of wood or light aluminum tubing, while the outside covering is fiberglass or aluminum sheet (AMG-M), with insulation being made of foam plastic with a specific gravity of 35 - 40 kg/m^3 ; the inside walls are covered with liderin or paper. There is a canvas "cold lock" in front of the entrance. The house is mounted on wood and metal or aluminum runners. The houses, which are pulled by reindeer teams, must not be more than 450 - 500 kg in weight, including the furniture and tools. One type of such moveable house for reindeer herders is shown in Fig. 25.

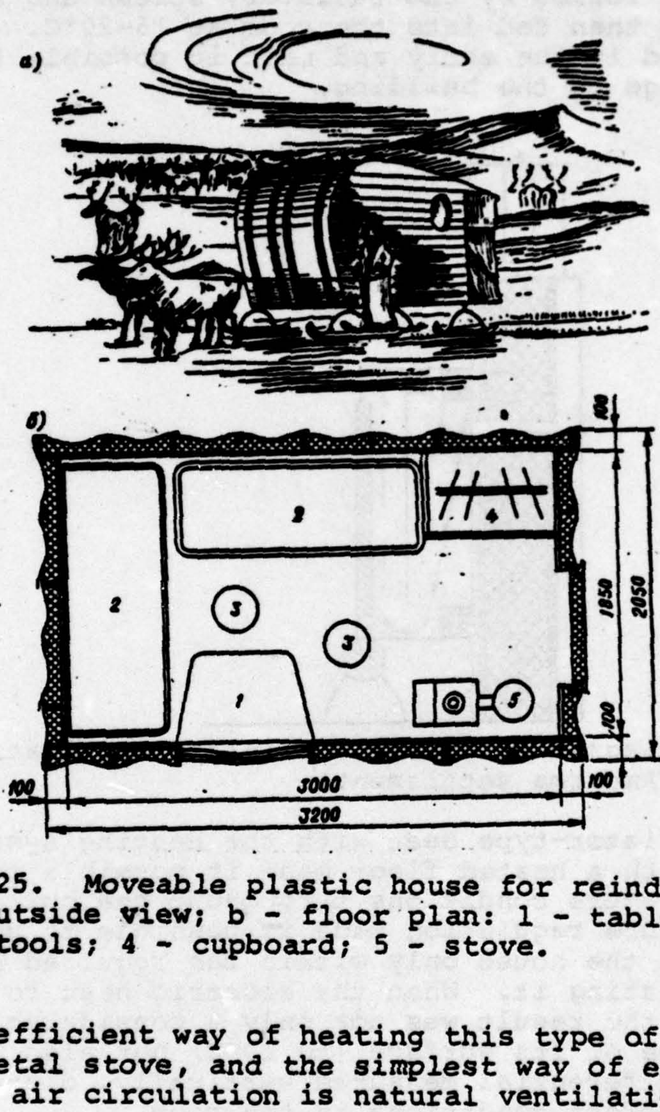

Fig. 25. Moveable plastic house for reindeer herders. a - outside view; b - floor plan: 1 - table; 2 - beds; 3 - stools; 4 - cupboard; 5 - stove.

The most efficient way of heating this type of house is a compact metal stove, and the simplest way of ensuring the necessary air circulation is natural ventilation through

specially provided openings. However, when natural ventilation is used, which depends upon gravitation and wind pressure, it is impossible to ensure constant air circulation. The majority of the air which enters the building is at low temperature and is pushed in by wind moving at high velocity. However, constant ventilation of the building by outside air at low temperatures produces uncomfortable conditions in the room. To avoid this problem it is a good idea to equip the house with a system which combines heating and ventilating functions simultaneously. A device of this kind could be a heater which operates on solid or liquid fuel.

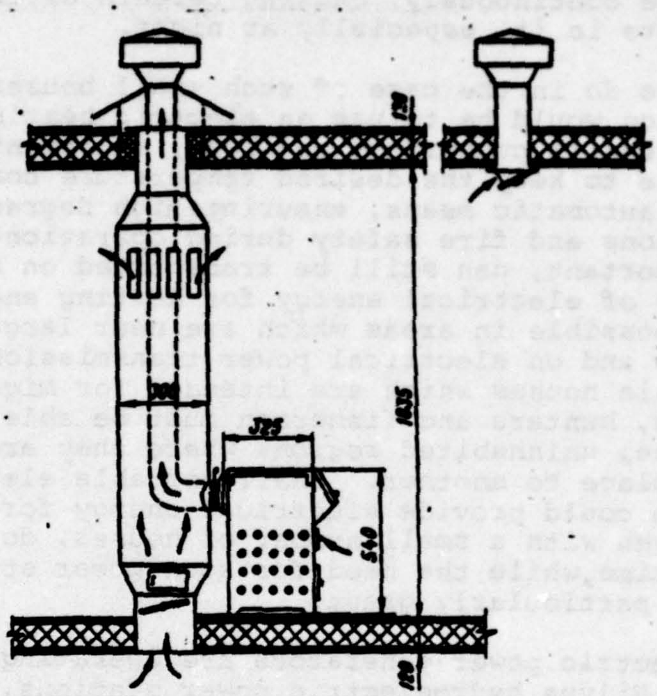

Fig. 26. Heating and ventilating assembly for a mobile home.

An experimental model of a heating and ventilating system for mobile homes, developed by LenZNIIEP (G. Ye. Brodsky) consists of a heater (Fig. 26) composed of two parts: a fuel tank intended for holding solid fuel and a heater for heating the outside air that comes through it into the room.

Preliminary tests of the heating and ventilating unit during the autumn and winter of 1971 - 1972 at Leningrad (when the outside temperatures reached +5 to -35°C) demonstrated that when the stove was burning the temperature in the house could be kept within acceptable limits (18 - 24°C), and the air coming in through the heater provided the necessary

change of air in the room five to eight times. However, since the heated air (at temperatures of 30 - 35°C) entered the room from the heater 20 - 30 cm from the ceiling, heating it, and the floor in the house did not show any temperatures above 10 - 12°C, there was a considerable temperature differential with height in the room which reached 10 - 15°C, which could have an unfavorable effect on the temperature comfort of people inside. Increased unilateral radiant heating of individuals by the heater is also a cause of an uncomfortable heat situation in the room. Minimum thermal stability of the house makes it necessary to fire the stove continuously, causing certain difficulties for those who live in it, especially at night.

The best thing to do in the case of such small houses with light construction would be to use an electric heating system which does not require cumbersome and heavy equipment and makes it possible to keep the desired temperature conditions in the rooms by automatic means, ensuring a high degree of hygienic conditions and fire safety during operation and, what is most important, can still be transported on skids. However, the use of electrical energy for heating and ventilation is only possible in areas which are near large electrification centers and on electrical power transmission lines, while the moveable houses which are intended for migratory reindeer herders, hunters and fishermen must be able to operate in remote, uninhabited regions where they are often moved from one place to another. Small portable electric generators which could provide electrical energy for individual units, even with a small number of houses, do not exist at the present time, while the need for such power stations in the North is particularly great.

When the new electric power generators are operating, the Krasnoyarsk and Vilyus hydroelectric power stations, the Bilibin nuclear power station, and later on the Ust'-Ilimsk, Shushinsk and other stations in Siberia and in the northern part of our country supply more and more of this inexpensive electrical energy, which can be used for residential needs and especially for electric heat for buildings. The power transmission lines which cover vast territories make it possible to supply electrical power even to the remote regions of the Soviet Union, permitting solution of a number of problems associated with the use of hot-water heating systems for buildings in the North.

INSULATION OF INDOOR PIPES

Continuous operation of engineering communications, especially water supplies, is extremely important for the daily activity of people living in the North. A prolonged interruption of the water causes a shutdown of the heating system and consequently interrupts the supply of heat to the buildings, which in these regions is a catastrophe and could make it necessary to evacuate the population temporarily.

Therefore, considerable attention must be devoted to problems of planning inside plumbing, and ensuring that it operates reliably. Improperly built pipes can cause uneven settling near the buildings where they are located, deformation of structural material, and even collapse.

In view of the difficulty of carrying out construction work in the North it is necessary for the construction of plumbing systems to consist of reinforced sections of pipe, finished assemblies, and prefabricated sanitary technical units, and to use prefabricated elements for heat insulation.

In designing residences and apartments in the North, several planning solutions are a favorable reflection of the work of the inside plumbing and reduce their cost. In particular, the perimeter type of construction of apartments not only cuts down the snow tracked into the buildings, but also promotes a decrease in the number of inlets from the outside pipe network.

In northern regions, in accordance with existing standards of construction, either type I or type II can be used. Buildings built according to type I, for preservation of soil which is subject to settling when thawed, have ventilated (breezeway) floors, where the air temperature is approximately equal to the outside temperature. In this case, it is possible to lay the pipes beneath the floor if ample insulation is provided. The subfloor area is about 1.2-1.5 m clearance. A concrete platform is laid beneath the pipes, onto which any leakage can flow in the event that the pipes should rupture, draining away into the sewer system; in the event of a satisfactorily local relief, they can be drained directly to the outside. When constructing according to this principle, special ducts can be left in the floor structure of the second floor, covered by panels, in which all of the pipes are laid, thus preventing them from freezing.

In constructing type II buildings in cases when there is no danger of the ground sagging when the soil thaws, the structure of the floor of the second story or the breezeway can be mounted directly on the ground, using foundations that

correspond to this design, and which are established by construction standard requirements. In this case, the pipes are laid in the breezeway, the service area beneath the floor, or special ducts, likewise with heat insulation.

The most favorable design from the standpoint of operational reliability of the water supply and sewer systems is the maximum mass production of the sanitary facilities for the purpose of reducing the lengths of the drainpipes, ensuring an adequate drainage of water, and consequently constant movement of the water and sewage in the pipes and drains. This same purpose is served by reducing the lengths of pipe leading out of the buildings and those leading in.

The main pipes should be laid in the breezeway, not around the perimeter of the building but in the central part near the lengthwise axis. In this arrangement, pipes for all purposes are located in the same place, thus reducing the length of the pipes and making it easier and simpler to protect the soil and the foundations of the buildings against water in the event of leaks and breaks.

However, experience has shown that the type of heat insulation which is used breaks down quite rapidly; it is very difficult to repair the pipes and apply insulation. Therefore these pipes which are laid in the breezeway beneath the floor cannot be completely protected against freezing, especially at night, when the water flow and amount of waste water cease almost completely. The pipes in the heating system, both the feed and return pipes, are almost never laid in the breezeway.

The most suitable and advantageous method of laying the pipes between buildings is to locate them in a special space beneath the floor, located between the covering over the floor with the breezeway beneath and the floor of the second story of the building. The breezeway must be at least 1.6 m from the projecting parts. In this arrangement, any water leakage runs along the bottom of the channel and outside the limits of the building, thereby completely preventing any danger of the ground beneath the building becoming soft.

At the present,time, steel and cast-iron pipes are used for internal water supply and sewer systems. They have poor heat insulating properties, considerable weight, are subject to corrosion, and burst when water freezes in them. This is particularly dangerous where cast-iron pipes join.

An analysis of the properties of plastic pipe indicates that stabilized elastic polyethylene pipe with a high resistance to frost (down to -60°C) and low thermal conductivity (0.25-0.32 kcal/m/hr/°C) are most promising, for use in the North.

The coverings for the supply and drain pipes in northern regions under normal conditions (nonseismic and with no permafrost) have no special characteristics in contrast to the methods and design solutions usually employed. However, in places where permafrost is the base on which the pipes are laid, it is necessary to eliminate any possibility of action of heat on the earth in the event of leakage of the material being transported in the event of emergencies.

The feed pipes and drain pipes, when laid in a zone with permafrost, can be separated into two different groups: above-ground pipes, which are not laid in channels and in channels on low supports, and the below-ground pipes, which are of the type without channels and with channels.

Laying the pipes above the ground makes it possible to largely rule out any thermal effects of the pipes on the ground beneath. This is why it is recommended to use them in permafrost areas. The use of this system of laying pipe is advantageous in small populated areas where the buildings are only one or two stories high, where the system is possible under the conditions of planning within the apartment complexes and also for temporary construction.

Underground supply and drain pipes must be designed for complexes with dense multistory buildings, where it is not permissible to lay the pipes on the surface. The non-ducted underground system of laying pipe can be used for individual low-temperature pipes no more than 300 mm in diameter.

Underground sewer pipe is used when constructing combined systems of water supply (cold and hot) and sewer pipe. In all cases, the underground feed pipes must be built so that they do not sag more than certain permissible amounts when the ground beneath thaws, so that a partial replacement of the permafrost by sandy soil must be carried out beneath the pipes and sewers in places where thawing might occur. In addition, the channels for the supply and sewer pipes must be equipped with a natural ventilation system which cuts down the heat effect on the soil considerably.

When using any of the recommneded methods, it is necessary to perform calculations which will govern the choice of parameters for protection - the thickness and the nature of heat insulation, the intensity of the flow, the pressure, the rate of flow of the liquid in the lines, etc. It is also necessary to determine the safe distance between the location of the feed pipe relative to the building foundations, ruling out possibility of any unexpected effects of a pipe which gives off heat on the permafrost foundations.

The following types of pipe must be used for the supply and drain pipe:

For carrying water for below-ground and above-ground pipelines in channels and without channels - steel electrowelded pipe according to GOST 10704-63 and steel seamless pipe according to GOST 8732-70;

For the heating system - steel electrowelded pipe, GOST 10704-63;

For sewers to be installed above and below ground, without channels - steel seamless pipe according to GOST 8732-70, for laying in channels - steel seamless pipe, GOST 8732-70 and cast-iron water pipe, GOST 5525-61.

Steel pipe provides the necessary protection for supply pipes and drain pipes as far as reduced sensitivity of welded joints of the pipe to temperature deformations and effects comparative to other types of connections. For pipes, it is necessary to use killed "quiet" steel. For installation without channels, steel pipe must be covered by anticorrosion substances.

The pipe junctions in cast-iron sewer pipe must be packed with a soft caulk - asphalt mastic. In the case of non-channel underground installation of sewer pipes, it is not permissible to use cast-iron pipe.

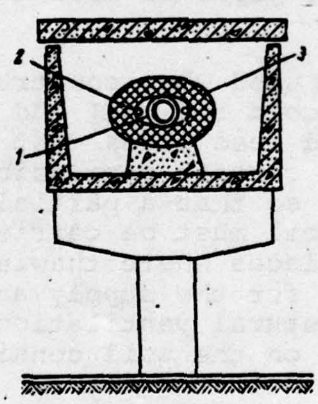

Fig. 27. Installation of pipes with heating system.
1 - sewer pipe; 2 - pipe from the heat supply network; 3 - heat insulation.

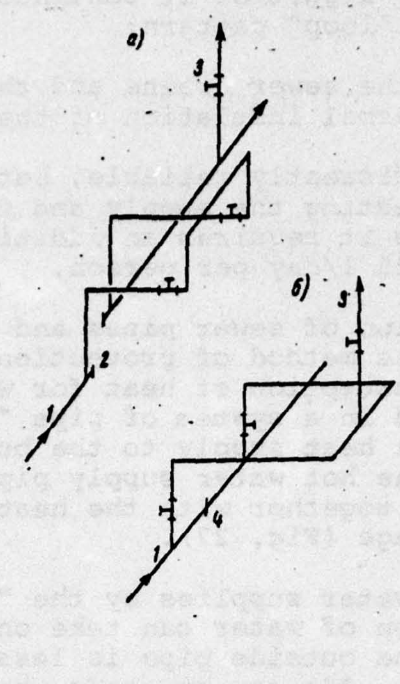

Fig. 28. Device for installation according to the "loop" system.
a - with a diameter of the outside pipe equal to 100 mm; b - for pipe diameters above 100 mm: 1 - outside line; 2 - distribution network in the building; 3 - valves; 4 - diaphragm.

The supply pipes and drain pipes for the engineering system must be set up so that the material being transported is prevented from freezing and both the supply and drain pipes as well as the buildings are protected. This protection can be disrupted as a result of the thermal action of the pipes on the soil which forms the foundation of the building and the adjacent areas.

To prevent freezing of the liquid in the supply and drain pipes, the following methods can be employed:

Forced feed of tap water into the sewer line through the sanitary facilities in the building - simple flushing;

Laying the sewer lines with a heating system, i.e., installing a special pipe with a heat-carrying substance along with the sewer pipe in a common heat-insulating package;

Constant circulation of water in the water inlet pipe, when all of the flow or a part of it continuously circulates through the input in a "loop" pattern;

Electrical heating of the sewer drains and the water supply pipes; - dependable thermal insulation of the pipes.

Simple flushing is sufficiently reliable, but it is not an economical way of protecting the supply and drain pipes against freezing, since it requires an additional water consumption of 15 to 125 l/day per person.

The combined installation of sewer pipes and water supply pipes is a very reliable method of protection, but it requires additional consumption of heat for warming the pipes. It is installed in a system of pipe "loops," which are tapped off from the heat supply to the buildings. Both pipes in the "loop," the hot water supply pipe and the return pipe, are laid together with the heated pipe in a common insulation package (Fig. 27).

The system for laying water supplies by the "loop" system for constant circulation of water can take one of two forms. When the diameter of the outside pipe is less than 100 mm, the system shown in Fig. 28a can be used; when the supply is an element in the main pipeline and, regardless of the consumption of water in the building, there will be a circulation of water through the inlet. However, in this system in the event of a break the main pipe must be shut off.

The second system (Fig. 28b) is used when the outside pipe diameter is greater than 100 mm. For small consumption levels in the supply line, this type of system is not a reliable protection against freezing.

ELECTRICAL HEATING OF PIPES

Electrical heating of pipes is widely used owing to its technical advantages - the possibility of remote control and complete automation. It can be accomplished in two ways. The first is based on the fact that the heated pipe is used as an electrical resistor and is connected directly to the electrical power line. This method is used in pipes with welded or bell-and-spigot joints. In view of the requirements for safety and the insignificant electrical resistance of the pipes, they are connected into the line at reduced voltage, not above 65 v, with alternating current, since direct current causes electrolysis causing the metal to corrode.

When this method is used for heating, an electric wire with a cross section of 120-150 mm^2 is used to supply the current to the drain pipe; the wire is connected to the domestic power source through a transformer which supplies the necessary voltage. Up to the point where the wire is connected to the pipe, it is fed through a piece of gas pipe 75 mm in diameter which runs paralled to the drain; it is covered with insulation to reduce unproductive heat losses.

The wires carrying the current are connected to the drain pipe: one wire is connected to the outlet of the drain from the building and the other to the sewer chamber. The connecting contacts, clamps, are made of brass or steel rings. Between the clamp and the pipe to be heated, strips of lead are placed. In order to reduce the leakage of current from the pipe which is heated, it is electrically insulated from contact with the ground, walls and floors of the building.

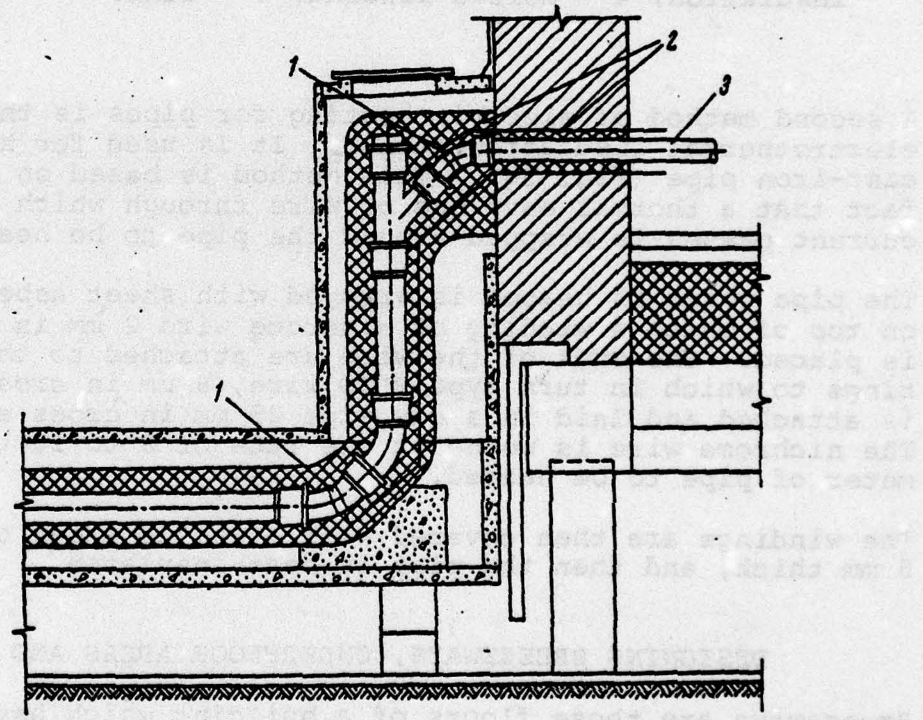

Fig. 29. Heating pipes by the electrical resistance method. 1 - metal clamp; 2 - heat insulation; 3 - pipe.

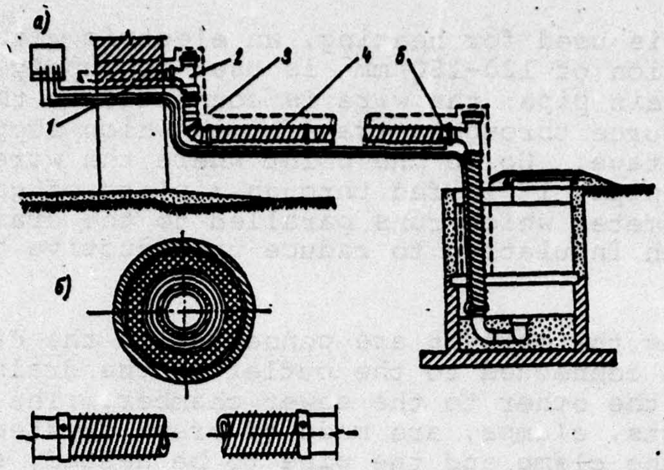

Fig. 30. Electric heating of pipes using the electrothermal insulation method.
a - heating line; b - pipe windings for electrical heating; 1 - electric wire; 2 - pipe; 3 - thermal insulation; 4 - coiled winding; 5 - tank.

A second method of electric heating for pipes is the electrothermal insulation method. It is used for heating cast-iron pipe (Fig. 30). This method is based on the fact that a thermal envelope of wire through which electric current passes is wrapped around the pipe to be heated.

The pipe which is heated is wrapped with sheet asbestos, on top of which a winding of nichrome wire 2 mm in diameter is placed. The ends of the wire are attached to the copper rings to which in turn type PRTO wire, 6 mm in cross section, is attached and laid in a gas pipe 25 mm in cross section. The nichrome wire is wound at the rate of 8 to 20 turns per meter of pipe to be heated.

The windings are then covered with a second sheet of asbestos, 5 mm thick, and then the pipe is heat-insulated.

DESIGNING BREEZEWAYS, UNDERFLOOR AREAS AND SERVICE LEVELS

Breezeways are those floors of a building which have parts of the floor below the sidewalk level or bridges more than half the height of the building. The design solutions and the heights of these breezeways must be determined by the conditions of their technical and economic operation.

Technical breezeways include those areas which are located beneath the second stories of buildings and have reduced height, sufficient only for engineering applications with pipes in them, but not for economic utilization of the space.

The breezeways and engineering areas, in addition to being used for engineering and economic functions, simultaneously serve as ducts which separate the building from the ground, places in which biological processes can take place, and which are to some extent saturated with water and therefore capable of affecting the physical characteristics of the building as a whole and especially the second floor.

The technical stages are intended primarily for locating engineering communications for tall buildings, when technical and requirements necessitate classifying the engineering devices by height or when various rooms are located on the lower floors which are crossed by plumbing lines, which serve the upper floors, which is not advantageous nor allowed. On the service floors, the service and auxiliary rooms are located.

The service levels can be located on the lower, middle or upper parts of the building, depending on their planning and structural characteristics and the parameters of the outside engineering networks, to which the inside plumbing of the house is connected.

The breezeways and spaces which constitute large air cavities, are in direct contact with the solid ground and have their own particular thermophysical conditions. They are characterized by the fact that during winter, and during the whole year in some cases, there is a tendency toward condensation of water vapor from the air. The earth, as a porous medium, when the parameters of the air in contact with it are appropriate, can either give off moisture to it or absorb moisture from it.

The outside and inside walls of the buildings in these breezeways and underfloor areas come in contact with the outside air, the soil, and the air from the buildings being heated - a medium which changes its parameters depending on the season of the year. The pipes which are laid in the breezeways and underfloor areas carry water at different temperatures. These conditions in many instances cause formation in the breezeways and underfloor areas of an unfavorable heat and moisture situation which promotes the formation of dampness which has a negative influence on all forms of insulation of pipes, promoting its damage and rusting

of the tubing. The reduced temperature of the environment then causes condensation of water vapor on them; at low temperature, they are subject to the danger of freezing. The water-carrying pipes, in addition, have unprofitable heat losses which increase under these conditions.

The contact of the exposed ground with the air causes the development of black flies and gnats, formatio of decay processes and unpleasant odors. All of these phenomena make it necessary to take special measures to eliminate them and ensure that there will be normal temperature and humidity conditions in the breezeways and service areas beneath the floor. For this purpose, the breezeways and service areas beneath the floor must have floors which prevent moisture from evaporating from the ground into the air of the buildings and saturation of the soil with moisture, which evaporates from the air and with a high level of ground water, preventing the latter from entering the breezeways and places under the floor.

When breezeways are used for economic or special purposes, the upper layers of the floors must correspond to the functions of the rooms.

Heat is transferred into the ground through the floors of the breezeways and underfloor areas; the magnitude of this process is a function of the depth at which the buildings are constructed, the thermophysical properties of the soil, the dimensions of the floor in square meters, the thickness and construction of the floor, the existence of mixed foundations, etc. In the central part of the floor the heat flux is less than in that part of the floor which is in contact with the outside walls. In many cases it is economically justifiable to reduce this heat transfer by heat-insulating the floor at the ground level, especially along the perim ter of the building. Attention should be given to this problem during the design stage.

The heat-insulating properties of the outside walls of the service floors must not be less than the walls of the main floors.

As mentioned earlier, the plinth walls must be heated, and the resistance to heat transmission R_o must be at least $0.85R_o^{тр}$ of the walls of the main floors. Moisture-impermeable materials must be used to protect the plinth against dampness from the soil and from precipitation. The heat-insulating properties of the outside walls of service floors must not be inferior to those of the walls of the main floors.

Coverings above breezeways, service breezeways and service floors must have an impermeability to air which is no less than that of the outside walls; they must be heated.

The breezeways which are not intended for economic use and those areas beneath the floors need not be heated, but they should be heated in accordance with the recommendations above, in order to maintain normal temperature and moisture conditions

in them and prevent condensation of moisture from the air. The spaces which are intended for economic utilization should be heated in accordance with the use to which they are to be put. The service floors should also be heated, and the recommended air temperature in them should not differ by more than 5°C from the air temperature in the adjacent floors.

The breezeways, spaces beneath the floor and service floors must have natural ventilation with a frequency of 1-3 air exchanges. In order to ensure that air is drawn into the outside walls of the engineering-service floors, it is necessary to provide openings whose total area must be at least 1:500 of the area of the subfloor area. The openings must be located on both sides of the rooms with transoms which open inward and glazed transoms that open. The breezeways and service floors must be provided with windows which open.

To prevent air from leaking into the floors above and to intensify ventilation of the subfloor areas, breezeways and service floors during winter, air must be exhausted from them through normal exhuast ducts, which must be provided in the inside walls.

The breezeways, subfloor areas and service floors must satisfy the conditions requiring the installation and operation of service lines in them. Each type of service line has its own installation area owing to the technological characteristics of the individual type of system and its accessibility based on the conditions under which it is installed relative to the other systems. It is advantageous to distribute the lines as follows: heating, distributing and return pipes, connected directly to the risers of the system, must be located on the outside walls at a sufficient distance from their surfaces so that thermal insulation for the pipes can be easily installed. When the breezeways are not heated, the main pipes must be installed above the door openings. When the subfloor areas are heated, the mains are mounted so that bypasses for different openings are eliminated. The heating lines, which intersect the subfloor areas diagonally, are located so that they do not intersect the working passageways at places and levels which are uncomfortable for service personnel.

The water pipes must be laid in the upper parts of the inner walls or above the covering without intersecting it through openings and passageways. The pipes for sewers in subfloor areas and breezeways which do not have channels in them are laid beneath a covering, while in those areas provided with channels they are laid in the floors, likewise not intersecting the openings and passageways.

In breezeways, subfloor areas and service floors it is not allowed to install gas pipes (both those serving the building or passing through it).

It is economically and technically advantageous to lay the through-heating lines along the breezeways and technical subfloor areas of buildings both lengthwise and transversely when the pipes are no more than 300 mm in diameter. These pipes must be located in a special zone, supporting them on low rests on the floor, allowing service personnel access to them.

All of the pipes which are laid in the subfloor areas, breezeways and service floors must be provided with insulation: hot insulation for hot-water pipes and cold insulation to prevent condensation of moisture on their surfaces.

The heating points and elevator assemblies must be located in separately insulated dry locations which are easily accessible for service personnel. These locations must be equipped with artificial illumination, water pipes, sewers (if possible, in ducts). The heating points must be located along with the elevator and water-measuring assemblies in one place. The dimensions of the rooms for the heating locations and elevator installations must make it possible to have normal servicing of the equipment located in them as well as the pipes as follows: the height of the rooms must be at least 2 m and at least 1.8 m up to the projecting parts; the width of the passageways to the projecting parts of the equipment and construction must be at least 1 m; the height of the doors must be at least 1.8 m; the location of the supporting framework must allow free operation with a wrench on flanged connections; the location of monitoring and measuring instruments must be convenient for readings to be taken.

The subfloor areas in which through pipes are laid must be at least 1.8 m high to the projecting parts, and in the event there are no through pipes they should be no less than 1.6m; in breezeways the height should be at least 1.8 m to the projecting parts. The inlets to technical service areas beneath the floor and breezeways must be equipped with convenient staircases with handrails.

The height of the doors should be at least 1.6 m, and they should open outward.

All of the rooms in the subfloor area and breezeway with pipes through which the operating personnel must pass must have artificial illumination; the equipment must correspond

to requirements for locations with high humidity. The light switches must be located at the entrances.

In order to make it possible to replace pipes in the subfloor and breezeway areas, it is recommended that the ends of the building plinths be provided with special mounting openings measuring 0.8 x 0.8 m, whose provision must not be connected to the structure of the building walls.

The height of the service floors must be at least 1.8 m to the projecting parts. All of the rooms of the service floors, through which pipes are laid and through which service personnel must pass, must have natural and artificial illumination.

In the transverse supporting structures of buildings, walls and partitions, intersecting subfloor areas, breezeways and service floors, it is necessary to provide openings to pass pipes through and for service personnel to pass through. The dimensions of the openings must correspond to those allowing the pipes to be passed through along with insulation both vertically and horizontally, taking into account free access to them and work with tools during repair. The dimensions of the openings for these passageways must be at least 1 m wide and 1.8 m tall in the case of breezeways and 1.6 m for subfloor areas. It is permissible to construct a threshhold ho higher than 0.3 m when the level of the top of the sill is 1.8 m from the floor and 1.2 m wide.

When ventilation chambers are installed in breezeways, subfloor areas and service floors, it is necessary to provide special insulated dry rooms whose dimensions must make it possible to service normally the equipment located in them, pipes and air ducts: the height of the room must be 0.5 m greater than the height of the equipment in it, and the width of the passageways to the access areas to the equipment and construction must be at least 1 m, and the doors must be at least 1.8 m high. In the case of large equipment, it is necessary to have mounting openings, which allow the largest elements of the equipment to be passed through. The locations of these openings must not conflict with the structures of the supporting chambers and rooms of the building.

Provision must be made in the ventilation chambers for measures to absorb noise and sound. The air ducts, laid in the breezeways, subfloor areas and service floors must allow access for operation and repair.

VOLUME-PLANNING SOLUTIONS FOR BUILDINGS

In designing buildings for the North, it is necessary to take into account the climatic effects not only on the buildings but also on the way of life of the people. Usual volume-planning solutions, which are characteristic of the central regions of the country, are unsuitable here. The data from various studies indicate that in the northern regions the standards for the air volume per person must be increased by 20% in contrast to that which is usually employed. This fact influences the increase in the size of the rooms and the working areas in buildings for general use.

In high-latitude regions, in order to ensure standard natural illumination of rooms it is necessary to increase the window areas or to reduce the depth of the rooms. Inasmuch as the microclimate suffers with this solution, it is more advantageous to increase the window area and widen the rooms. Widening the rooms is advantageous from the heat engineering standpoint as well because it cuts down the ratio of the perimeter of the building to its area and thereby cuts down the surface of costly outside wall and the heat loss from it consequently reducing heat consumption and operating expenses.

Increasing the width of the room in many cases requires shifting the staircases into the interior, necessitating that they be illuminated only by artificial light, and therefore it is necessary to have reliable ventilation. In some proposed solutions, in order to reduce the heat losses in the buildings, it is suggested that the kitchens be located in the middle of the apartments, so that they lack natural illumination. From the hygienic and psychophysiological standpoint, the construction of dark kitchens, even when they are fitted with electric hotplates and controlled, is extremely undesirable because, since they are a part of the apartment, the kitchen is a place where people stay for a long time and therefore should not lack natural illumination. Planning solutions for wide rooms in buildings should not cause any deterioration of the hygienic and fireproofing qualities of the housing.

At LenZNIIEP, the structural and planning solutions of sections of houses with expanded floor areas were analyzed from the heat engineering standpoint. As a result of this analysis, the calculated heat losses were determined by sections, annual heat and fuel consumption, as well as the cost of the heat, calculating it for the section as a whole and per m^2 of useful area with heat being supplied from a central heating station. These analyses indicate that the

calculated heat losses through the walls of four- and nine-story sections make up almost the only parts of total heat losses. Thus, in row sections, they amount to 32-33%, while at the ends they amount to 40-42%. In all cases, the specific heat losses from the wide rooms were less than for the ordinary type.

The study of statistical data on illness in northern cities indicates an increase in the number of colds in comparison with central temperate regions, which is due to the considerable temperature drop between the air in the rooms (18-22°C) and the outside air (an average of -35 to -40°C).

In order to eliminate these phenomena it is advantageous to build rooms which prepare the human organism for the transition from the warm rooms to an environment with a low temperature and high wind velocity; these auxiliary rooms, reduce the number of times that people have to go outside into the harsh climate; they also include special rooms for taking off and putting on clothes, storing the seasonal clothing. They include locks of different kinds, covered passageways, special storage areas for keeping supplies and products, drying chambers for clothing in apartments, wardrobes with dryers in public buildings, storage areas for fuel, rooms for baby carriages, etc.

In view of the high calculated temperature differential in northern regions and the resultant considerable infiltration of outside cold air into the apartments on the lower floors, it is necessary in northern areas to limit the construction of tall buildings. In regions with a calculated temperature of -40°C and less, no buildings higher than nine stories should be built. In those regions where the wind speed is in excess of 5 m/sec, it is not recommended that apartments be designed with through ventilation.

In regions where snowstorms occur often, with an intensive blowing of snow horizontally, special attention must be given to the aerodynamic characteristics of the buildings.

It is not recommended that typical buildings be designed for all northern zones; they must be designed for the different subzones, taking climatic features into account in each case.

In buildings with a number of stories it is necessary to provide some engineering measures for hermetic sealing and warming of the staircases; double doors must be installed at the entrances, with three doors, the door edges must be sealed, the minimum number of entrances to the building must be provided and they must be located away from the staircases.

The entrances to the apartments in the buildings, no matter how high they are, must be double, with sealed edges.

The design of the individual and specific buildings with a number of stories or with a large volume and considerable capacity must be subjected to preliminary modeling of the air volume or aerodynamic testing on models which simulate the thermophysical conditions.

Appendix 1

Saturated partial pressures of water vapor (E, mm Hg) for different temperatures and normal barometric pressure

For negative temperatures from 0° to -30° (above ice)

°C	0.0	0.2	0.4	0.6	0.8
0	4,58	4,51	4,44	4,36	4,30
—1	4,22	4,15	4,08	4,01	3,95
—2	3,88	3,82	3,75	3,69	3,63
—3	3,57	3,51	3,45	3,39	3,34
—4	3,28	3,22	3,17	3,11	3,06
—5	3,01	2,96	2,91	2,86	2,81
—6	2,76	2,72	2,67	2,63	2,58
—7	2,53	2,49	2,45	2,41	2,36
—8	2,32	2,28	2,24	2,20	2,17
—9	2,13	2,09	2,05	2,01	1,98
—10	1,95	1,91	1,88	1,84	1,81
—11	1,78	1,75	1,72	1,69	1,66
—12	1,63	1,60	1,57	1,55	1,52
—13	1,49	1,46	1,43	1,41	1,38
—14	1,36	1,34	1,31	1,29	1,26
—15	1,24	1,22	1,19	1,17	1,15
—16	1,13	1,11	1,09	1,07	1,05
—17	1,03	1,01	0,99	0,97	0,96
—18	0,94	0,92	0,90	0,88	0,87
—19	0,85	0,83	0,82	0,80	0,79
—20	0,77	0,76	0,75	0,73	0,71
—21	0,70	0,69	0,67	0,66	0,65
—22	0,64	0,62	0,61	0,60	0,59
—23	0,58	0,56	0,55	0,54	0,53
—24	0,52	0,51	0,50	0,49	0,48
—25	0,47	0,46	0,45	0,44	0,43
—26	0,42	0,41	0,40	0,39	0,38
—27	0,38	0,37	0,36	0,35	0,34
—28	0,34	0,34	0,33	0,33	0,32
—29	0,31	0,30	0,29	0,29	0,28
—30	0,28	0,28	0,27	0,26	0,23
—31	0,25	0,25	0,25	0,24	0,23
—32	0,23	0,23	0,22	0,22	0,21
—33	0,20	—	—	—	—
—34	0,18	—	—	—	—
—35	0,17	—	—	—	—

For positive temperatures from -0° to +40°C (above water)

°C	0,0	0,2	0,4	0,6	0,8
0	4,58	4,65	4,72	4,79	4,86
1	4,93	5,00	5,07	5,14	5,22
2	5,29	5,37	5,45	4,43	5,61
3	5,69	5,77	5,85	5,93	6,02
4	6,10	6,19	6,27	6,36	6,45

Appendix 1 continued

°C	0,0	0,2	0,4	0,6	0,8
5	6,54	6,64	6,73	6,82	6,92
6	7,01	7,11	7,21	7,31	7,41
7	7,51	7,62	7,72	7,83	7,94
8	8,05	8,16	8,27	8,38	8,49
9	8,61	8,73	8,85	8,97	9,09
10	9,21	9,33	9,46	9,59	9,71
11	9,84	9,98	10,11	10,24	10,38
12	10,52	10,66	10,80	10,94	11,09
13	11,23	11,38	11,53	11,68	11,83
14	11,99	12,14	12,30	12,46	12,62
15	12,79	12,95	13,12	12,29	13,46
16	13,63	13,81	13,99	14,17	14,35
17	14,53	14,72	14,90	15,09	15,28
18	15,48	15,67	16,87	16,07	16,27
19	16,48	16,69	16,89	17,11	17,32
20	17,54	17,75	17,97	18,20	18,42
21	18,65	18,88	19,11	19,35	19,59
22	19,83	20,07	20,32	20,57	20,82
23	21,07	21,32	21,58	21,85	22,11
24	22,38	22,65	22,92	23,20	23,48
25	23,76	24,04	24,33	24,62	24,91
26	25,21	25,51	25,81	26,12	26,46
27	26,74	27,06	27,37	27,70	28,02
28	28,35	28,68	29,02	29,35	29,70
29	30,04	30,39	30,75	31,10	31,46
30	31,82	32,19	32,56	32,93	33,31
31	33,70	34,08	34,47	34,86	35,26
32	35,66	36,07	36,48	36,89	37,31
33	37,73	38,16	38,58	39,02	39,46
34	39,90	40,34	40,80	43,25	41,71
35	42,18	42,64	43,12	43,60	44,08
36	44,56	45,05	45,55	46,05	46,56
37	47,07	47,58	48,10	48,63	49,16
38	49,69	50,23	50,77	51,32	51,90
39	52,44	53,01	53,58	54,16	54,74
40	55,32	55,91	56,51	57,11	57,72

Appendix 2

Calculated temperatures and atmospheric humidity in residential buildings and public buildings

Type of building	calculated temperature °C	calculated humidity %
Residences		
In the first construction climate zone	20	45
In the second construction climate zone	18	30-60
Bathroom, combined with toilet	25	80
Kitchen, toilet, staircase	16	30-60

Type of building	calculated temperature °C	calculated humidity %
Kindergartens		
Children's rooms, toilets, nurse's room, corridors	20	60
Playrooms and showerrooms	25	75
Schools		
Classrooms, laboratories, playrooms, offices	16	60
Teachers' room, principal's office, offices, toilets, washrooms	18	60
Showerrooms	25	25
Hospitals		
Wards and rooms for adults	20	60
Ditto, for children	22	60
Pre-operation rooms, massage rooms	25	75
Bathrooms and showers	25	75
Movie theaters		
Auditorium, foyer	14	60
Projection room, smoking room, buffet, ticket office	16	60
Other buildings		
Administration buildings, stores, cafes, restaurants	18	50
Commercial buildings, food and meat stores	12	60
Ditto, shops selling consumer goods	15	60

Appendix 2 continued

Type of building	calculated temperature °C	calculated humidity %
Refrigerated storage areas	10	75
Commercial buildings, cafes	16	60
Kitchens and pastry shops	5	40
Places where food is prepared and sold	16	60
Places for washing dishes	18	70

Appendix 3

Arbitrary designations for heat engineering parameters and their dimensions

Type	Symbol	Units of measurement	
		Technical system	SI system
Coefficient of thermal conductivity of a material	λ	kcal/m·hr·°C	1.163 W/(m·K)
Coefficient of heat transmission of outside structure	k	kcal/m^2·hr·°C	1.163 W/(m^2·°C)
Resistance to heat transmission of an outside structure	R=1/k	m^2·hr·°C/kcal	0.860 m^2·K/W

Type	Symbol	Units of measurement	
		Technical system	SI system
Coefficient of heat loss of an inside surface of an outside wall	α_i	kcal/m^2·hr·°C	1.163 W/(m^2·K)
Specific thermal capacity of a material	c	kcal/kg·°C	4187 joules/(kg·K)
Coefficient of heat absorption of material	s	kcal/m^2·hr·°C	1.163 W/(m^2·K)
Coefficient of heat absorption of the surface of an outside structure	Y	kcal/m^2·hr·°C	1.163 W/(m^2·K)
Value of the total solar radiation striking the outside surface of an outside wall	I	kcal/m^2·hr	1.163 W/m^2
Pressure of saturated water vapor	E	mm Hg	133.322 newtons/m^2
Partial pressure of water vapor	e	" "	133.322 newtons/m^2
Coefficient of vapor permeability of material	μ	g/m·hr·mm Hg	$2.08 \cdot 10^{-9}$ kg/(m·s·newtons/m^2)
Resistance to vapor penetration of the outside structure or its individual layers	R_v	m^2·hr·mm HG/g	$4.7996 \cdot 10^{8}$ (m^2·s·newtons/m^2)/kg
Coefficient of air permeability of material	i	kg/m·hr·mm water column	$2.83 \cdot 10^{-5}$ kg/(m·sec·newtons/m^2)
Calculated difference in air pressures	Δp	mm water column	9.807 newtons/m^2
Resistance to air permeability of outside construction	R_{os}	m^2·hr·mm water column kg	$3.5304 \cdot 10^{4}$ (m^2·s·newtons/m^2)/kg
Air flow through outside structure	G_o	kg/m^2·hr	$2.8 \cdot 10^{-4}$ kg/(m^2·sec)

Appendix 3 continued

Type	Symbol	Units of measurement	
		Technical system	SI system
Temperature	t	°C	(°C+273)K

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